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

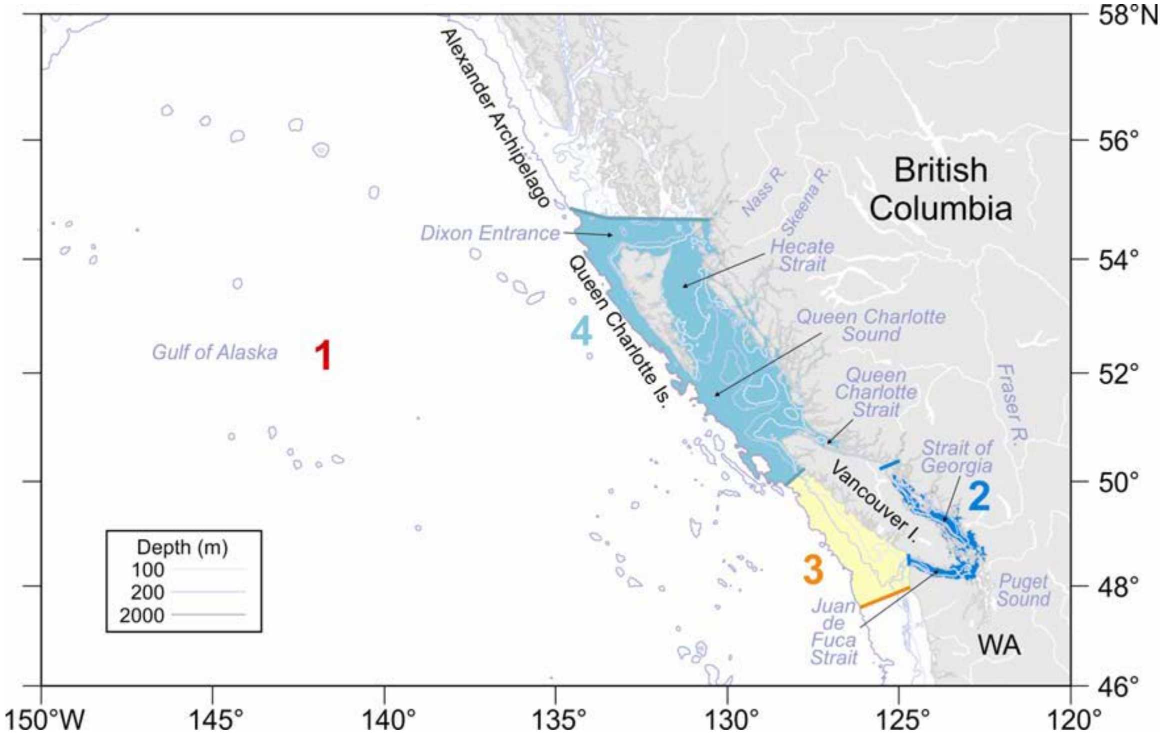

Figure 1: The four spatial sub-divisions of the Pacific Large Aquatic Basin (LAB): Gulf of Alaska (1), Strait of Georgia (2), West Coast of Vancouver Island (3), and Pacific North Coast (4). Included in this study are freshwater systems that support spawning and rearing of anadromous fishes.

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 basin or sub basin level in each LAB will be published in the 2013-2014 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 the Pacific 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 (*to be published*[1,2]).

This Science Response Report (SRR) details the results from the National SSRP meeting of November 28-29, 2012 on the Risk-based assessment of climate change impacts and risks on biological systems and infrastructure within Fisheries and Oceans Canada's mandate - Pacific Large Aquatic Basin, Nanaimo, British Columbia. The SRR resulting from this Pacific LAB and the other three SSRP LAB advisory meetings will be posted as they become available on the DFO Science Advisory Schedule.

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[1] Christian, J. R. and Foreman, M.G.G. 2013. Climate trends and projections for the Pacific Large Aquatic Basin. Canadian Technical Report of Fisheries and Aquatic Sciences. 3032: xi + 113 p.

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 Sci xxx (provisory title, unpublished manuscript)

Background

Climate change is an important 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 difficult to predict how, where and when the impacts will occur and at what magnitude. Furthermore, DFO is a complex and diverse Department for which there is a high likelihood that climate change impacts will affect all of its sectors and regions to some extent. 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.

Geographical Scope of the Pacific Large Aquatic Basin

Geographic components of the Pacific LAB that fall under the responsibility of the Department are the marine and coastal waters along the west coast of Canada, as well as rivers, lakes and streams bearing anadromous fishes. The characteristics of both marine and freshwater environments differ considerably across the region. There are four spatial sub-divisions of marine systems for the purposes of ACCASP: Strait of Georgia (SOG), West Coast of Vancouver Island (WVCI), Pacific North Coast (PNC) and Gulf of Alaska (GOA) (Fig. 1). The Gulf of Alaska, although not entirely under Canadian jurisdiction, is included in the study area. Freshwater systems that support spawning and rearing of anadromous fishes are located throughout the region and, in many cases, extend well into terrestrial zones (Fig. 1).

There is a varying degree of understanding of the marine components of the Pacific LAB. The GOA sub-basin comprises open-ocean environments that play an important role in the dynamics of coastal and shelf ecosystems as well as those of the broader North Pacific. Although understanding of marine ecosystems of this sub-basin is incomplete, we know it to be important for Pacific salmon marine rearing and survival. The remaining three sub-basins (SOG, WCVI, PNC) include a relatively well understood, highly-variable marine transition zone that is influenced by major offshore coastal currents (southward Alaska Current, northward California Current). Important wind and buoyancy driven coastal features (i.e. Vancouver Coastal Current, Shelf Break Current, Davison Current), estuarine flows in the SOG, seasonal eddies (Haida, Rose Spit, Juan de Fuca) and inputs from snow-melt or glacially-fed rivers along the coastline influence inshore sub-basins more directly. The Pacific LAB coastline features steep topography and bathymetry with a mountainous landscape containing an array of deep fjords and inlets (Thomson 1981). Prevailing landward winds drive patterns of coastal marine upwelling (summer) and downwelling (winter). Seasonal cycles of heavy precipitation and peaks of snow and glacial melt influence hydrographs (Whitfield and Cannon 2000) and drive localized and regional flood and drought dynamics. Together, ocean currents and major rivers exert strong effects on coastal circulation, nutrient delivery and primary production in the coastal marine ecosystems of SOG, WCVI and PNC. In addition, Fraser River inflows that are initially contained between the mainland and Vancouver Island strongly influence the SOG sub-basin (Thomson 1981, Masson 2006). Freshwater from the Fraser River later drives estuarine flows in Juan de Fuca Strait and the Vancouver Island Coastal Current.

The transition zone position of the Pacific LAB results in physical and chemical changes to the marine environment at seasonal to decadal time scales. The El Niño-Southern Oscillation (ENSO) events, as well as warm and cold-phases of the Pacific Decadal Oscillation (PDO; DFO 2006-2011; DFO 2010a) drive variability in the transition zone. Complex biophysical and multi-trophic-level impacts on biota result from this variability. In fact, biological responses to past climate variability (e.g. Beamish and Boullion 1999; King and McFarlane 2003) prescribe much of our understanding of the expected impacts from future climate change on biota in the Pacific LAB. These responses include the re-distribution of species during “warm ocean” years and alterations in growth and recruitment of Pacific fish species associated with variation in food-webs (Ware and Thomson 2005; Mackas et al. 2007; DFO 2006-2011; DFO 2010a). However, such responses have to date remained well within the range of historic variation (DFO 2006-2011; DFO 2010a) and anthropogenic climate change signals have yet to emerge from decadal-scale variability in the marine environment.

Freshwater environments in the Pacific LAB are experiencing the effects of climate change differently than coastal or marine zones. There are detectable effects of climate change on temperature, snow-pack and hydrology appearing in terrestrial aquatic systems in the Pacific LAB (Morrison et al. 2002; Tillman and Siemann 2011). Measured climate change in freshwater habitats is affecting Pacific salmon (e.g. SOG: Hinch and Martins 2011).

Biological Resources and Infrastructure Assets

Historically, fisheries in the Pacific LAB have sustained significant volumes and value of catch. In recent decades, commercial fisheries have been undergoing a transition involving harvest of a broader range of species (percent of landings by weight 2006-2010: groundfish = 42 %; pelagics = 25 %; shellfish = 33 %; DFO 2012) and have an average annual value of about $300 million. Wild Pacific fisheries have changed, in part, due to region-wide declines in salmon and herring abundance relative to higher levels in the 1980s (Hare et al. 1999; Schweigert et al. 2010), expansion of aquaculture production and invertebrate fisheries, and negotiation of catch shares to settle First Nations’ treaty claims (Pearse and McRae 2004). Some of these changes have also affected recreational fisheries occurring along the coast that contribute more than 120 million dollars annually to the British Columbia economy (DFO 2010b). First Nations Food, Social and Ceremonial (FSC) allocations are an important part of the Department’s obligations in the Pacific LAB. These fisheries occur across both coastal and terrestrial zones, including the upper reaches of major river systems. This constitutionally-protected harvest of Pacific fishes contributes key subsistence and cultural and societal benefits to First Nations.

The availability of sheltered, ice-free marine waters in the Pacific LAB provides suitable sites for aquaculture production. DFO‘S role related to aquaculture has expanded in British Columbia as a result of the recent BC Supreme Court decision. Currently, BC is the only province in which DFO licences the activity of aquaculture as a fishery. Aquaculture production has expanded from contributing less than 5% of the total fisheries volume or value to contributing more than 25% of the volume and 60% of landed value of all fisheries products. Salmon culture alone accounts for on average 89 % (79,000 tonnes) of the volume and 94% ($434 million) of total landed value of all British Columbia cultured fish (DFO 2012).

DFO owns and operates a number of important infrastructure elements in the Pacific LAB that contribute to achieving the Department’s multi-objective mandate. A suite of Canadian Coast Guard (CCG) and Small Craft Harbours (SCH) services are essential to meeting the goal of ensuring a safe and secure coastline through providing environmental and emergency response, navigable waterways and small craft harbours. Additionally, there is a large network of salmon enhancement facilities (i.e. hatcheries) in the Pacific LAB that are a central component of sustaining Pacific salmon fisheries that are governed, in part, by established treaties with the USA. Major marine facilities (i.e. Science branch facilities) and installations (i.e. lighthouses) and other freshwater works (i.e. field camps) are significant investments, that warrant consideration, but their assessment did not occur during this analysis.

Analysis and Responses

In preparation for this meeting, there was development of background and supporting information on climate trends and projections and biological and infrastructure oriented impacts, vulnerabilities and opportunities *(full reports to be published[3,4])*. Participants based risk evaluation on the presentation of background information in the form of a TP summary table and Risk Summary Sheets for each of the 6 aforementioned riss. Through the integration of their knowledge of each risk, participants provided science advice for the entire Pacific LAB. **The TP summary table (Appendix 1) and the six Risk summary sheets (Appendix 2-7) are the key advice resulting from this process.**

Trends and Projections

Pacific LAB experts generated projections for a series of climate drivers using Global Climate Models or regional ocean models forced with downscaled Global Climate Model output (Appendix 1). An initial objective was to generate projections for 10 and 50-year timescales. However, the highly variable nature of the north east Pacific Ocean climate precludes projections at the 10-year timescale, as described below. Meeting participants briefly reviewed the summary provided on Trends in climate change drivers. Review of the Projections information dominated the meeting discussion.

Trends and Projections in the Pacific LAB

Trends and projections information is the basis for understanding current and future climate conditions. Past observations establish a trend, although lengths of time series of different parameters at different locations vary. Projections from climate model outputs use assumptions about future anthropogenic greenhouse gas emissions to estimate the anthropogenically-influenced climate projections. In the Pacific LAB, observed high variability of natural physical climate drivers is large in the marine environment relative to the projected increase associated with the long-term anthropogenic change on 10-50 year time scales. This natural variability has consequences for the ability to make meaningful climate projections at shorter time-scales, especially for the marine environment.

Ten-year projections are best estimated as linear extrapolations of past trends, with the caveats that (a) only those based on relatively long time series provide robust future “projections” and (b) even these are only our best estimate of the long-term trend on which unpredictable short-term variability is superimposed, and not the total signal. The uncertainty associated with extrapolation of a trend depends on the length of the data record used to estimate the trend and the temporal extent of the extrapolation. On a 10-year time scale, it is possible to extrapolate present trends if the data record is sufficiently long (> 20-30 years), but as noted above, the natural variability in the Pacific LAB currently overwhelms the anthropogenic component. For this reason, we did not make projections for the 10-year timescale in the Pacific LAB.

[3] Christian, J. R. and Foreman, M.G.G. 2013.

[4] Pacific Large Aquatic Basin – IVO (provisory title, unpublished manuscript)

Climate model outputs are the basis of the 50-year projections provided here, and uncertainty is derived from three sources: (1) the forcing scenario (the greenhouse gas emissions used to force the model), (2) model error, and (3) model internal variability. The latter is analogous to the natural variability discussed above. A good model reproduces the general characteristics of this variability (e.g., the frequency and magnitude of events), but can never reproduce the timing of them exactly. Therefore model projections are only useful when averaged over longer periods (20-30 years has been used routinely). Projections for several important variables are not resolved at the Pacific LAB sub-basin scale, so information on future climates at that scale remains sparse (see Knowledge Gaps; Appendix 1).

In freshwater zones, credible climate projections at 10 and 50 year time scales for the Pacific LAB are available (e.g. PCIC 2012). Additional information on freshwater projections for air temperature, water temperature, precipitation, streamflow and lake stratification and levels was presented and reviewed by participants during the meeting (Appendix 1).

Projected changes to freshwater systems, particularly water temperature and streamflow, are especially important for characterizing impacts to Pacific salmon and other anadromous and coastal resident species at both 10 and 50-year timescales. However, the objective of this risk assessment was to assess combined risks to biological systems for all species, in all environments, across the Pacific region. Therefore, separate consideration of 10 and 50-year climate projections in freshwater and marine systems did not occur during the risk assessment (see Knowledge Gaps).

Risk Summary Sheet Preparation

We gathered relevant IVO information in two ways. First, a literature survey (Web of Science, AFSA, WAVES) was conducted on climate variation and change impacts pertaining to Risks 1-3. The literature survey resulted in a compilation of potential impacts and consequences for biological and infrastructure elements relevant to DFO. Findings from the literature survey reflected a gap in knowledge of numerically specific or conceptual linkages between climate projections and potential impacts to biota at the sub-basin scale (but see Harvey 2009; Johannessen and Macdonald 2009; Cheung et al. 2010; King et al. 2011; Ainsworth et al. 2011; Hinch and Martins 2011). Further, the survey revealed that there is scant literature on invasive species and species at risk relating to climate change drivers applicable to the Pacific LAB. Second, we relied on consultant reports for information on climate change impacts to infrastructure elements. Two consultant reports were delivered separately on aquaculture (Castledine 2012, unpublished report) and salmon enhancement facilities (i.e. hatcheries; Lill 2012, unpublished report). A published report on climate change impacts to DFO's small craft harbours was the main source of information for this infrastructure element (AMEC 2011). To the author's knowledge, information pertaining to Risk 4 (increased demand to provide emergency response) and Risk 6 (change in access and navigability of waterways) was not available in published form beyond information available in Interis (2005, 2012). The IVO elements investigated for the Pacific LAB are included in Table 1.

Table 1. Elements assessed in Pacific LAB's Risk summary sheets.

Biological/Infrastructure element
Commercially Harvested Species
Lower Trophic Levels
Marine Mammals
Species at Risk
Invasive Species
Transient Species
Aquaculture Species and Facilities
Small Craft Harbours
Salmon Enhancement Facilities
Search and Rescue, Environmental Response
Navigability of Waterways

Risk Summary Sheets

Participants from Science division, who are the primary experts in this field, reviewed six risk summary sheets that describe the main climate change risk drivers, consequences, opportunities and gaps for each of the previously identified Departmental climate change risks (INTERIS 2005, 2012; Appendix 2-7). The risk summary sheets are the key science advice going forward to further integrated meetings with additional DFO sectors.

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

Risk driver: an element, which alone or in combination, has the intrinsic potential to give rise to a risk.

Consequence: an outcome of an event affecting objectives, where the event is an occurrence or change of a particular set of circumstances.

Each risk summary sheet highlighted the main risk drivers and their consequences using a combination of TP information and IVO-related literature and/or expert knowledge. The risk drivers specifically link TP climate drivers with published or expert IVO information on climate impacts in the Pacific LAB. We also compiled a list of key gaps and opportunities from IVO sources. Note that several of the main risk drivers, consequences, opportunities and gaps were common to Risks 1, 2 and 3. Furthermore, the list of consequences, gaps and opportunities prepared for each risk, and developed further through plenary is not exhaustive.

Risk 7: Risk to Fisheries Management Systems

DFO maintains considerable soft infrastructure to support its operational and scientific activities in both the marine and freshwater environments in the Pacific LAB. Examples of soft infrastructure that apply to fisheries management include stock assessment tools and related management frameworks, fisheries licensing policies and structure, aquaculture licensing and regulation frameworks, species at risk management (recovery strategies and programs), Food, Social, Ceremonial and First Nations commercial fisheries management and co-management frameworks, Recreation fisheries regulation, and salmon head recovery management (Pacific Salmon Commission related).

Based on discussions among Pacific LAB experts ahead of the workshop, an additional Risk Summary Sheet for a 7th risk was prepared to be discussed at the meeting. Risk 7 addresses risk from climate change to ‘fisheries management infrastructure’ that is developed and operated by the Department. Risk 7 Summary Sheet was presented in order to make explicit the requirement for the Department to reflect on the multiple impacts that climate change will have on the tools currently used to make fisheries management decisions. For example, custom population models, which are the cumulative synthesis of decades of work, may fail and require redesign as ecosystems undergo change. Further, there is potential for a mismatch of changes in species distributions with current management processes and regulations that will require adaptation tools that sufficiently manage alterations in key resources. Amplification of the impact from climate change on fisheries management infrastructure in the Pacific LAB is of concern because of the pelagic nature of harvested species that respond quickly to changes in oceanic conditions.

Participants decided that is was important to highlight climate change impacts to soft infrastructure in the SSR, but were not prepared to undertake a complete evaluation of Risk 7 at the meeting. Participants also noted that for the purposes of the current exercise, the other six risks sufficiently captured risk drivers concerning Risk 7. Although not included in this advice, the group agreed that future risk assessments should address climate change risk to fisheries management systems and other “soft infrastructure” elements that represent the operational tools required for the provision and interpretation of Scientific Advice.

Risk Summary Sheets Discussions

Meeting discussions identified that there are two kinds of information gap: 1) those that identify research needs and 2) those that arise from existing information that was not captured in the analysis. Risk summary sheets list gaps that identify areas with substantive research need.

Risk to Biological Resources

During the review of the biological risks (Risks 1-3) participants were careful to review and assign specific TP climate drivers (i.e. temperature, salinity) to a risk driver. Comments applicable to Risks 1-3 (biological risks) included discussion around several unknowns including: 1) impact of melting glaciers (inland) on contaminant distributions; 2) uncertainty of whether incidence of outbreaks of harmful algal blooms are linked to climate change drivers; 3) impact of ocean acidification on commercial fisheries. Information on aquaculture was included as it is a fishery managed by DFO. Participants noted that risks to invertebrate aquaculture from increasing temperature are likely low, given that most species are at the northern limit of their range, but that increasing acidification may have substantial effects on some species. Participants discussed the importance of identifying ocean acidification as a separate driver of change, as it is an indirect consequence of climate change.

Participants requested an iteration of the definition of a transient species in the advice.

> *Transient species* - Species whose temporary occurrence in a water body or biogeographic region outside its natural range is due to unusual climatic conditions (e.g., El Nino) or behavioral incursions. By definition, a transient population is not established (Lee et al. 2008). In special cases, such as transient orca populations, this definition does not apply.

Risk to Hard Infrastructure

Participation by two CCG officials provided information that aided to revise and create risk statements for risks of increased demand to provide emergency response (Risks 4) and changes in access and navigability of waterways (Risk 6). During review of Risk 4, participants noted that information on the frequency of storms (current and future) was not included in the assessment. Experts in this areas noted that analyses that are underway on this topic were not available for the meeting. CCG addressed a concern about lack of information on ocean forecasting in inland waters by stating that it does not conduct Search and Rescue activities in inland waters and has limited responsibility for Emergency Response in freshwater environments. Unlike other LABs, there is no sea ice or icebergs in the Pacific LAB.

The review of the risks of infrastructure damage (Risk 5) summary sheet involved the removal of a threat regarding aquaculture, as the Department's responsibilities do not extend to infrastructure at aquaculture sites. The inclusion of a biofouling risk driver addressed a concern about risk to water intakes and vessels used at aquaculture sites. Participants noted that such vectors could exacerbate this threat by spreading invasive biofouling species.

Risk Evaluation

We used the reviewed risk summary sheets to assess the impact of climate change to each of the six Departmental risks. Participants also assessed for each risk the probability that the amalgamated impact of all risk drivers would occur within either 10 or 50-year time scales.

Following the review of risk summary sheets, participants went through a formal process to assess Departmental risk using pre-established criteria (Appendix 8). Participants voted on the level of impact of each risk to the Department, and the probability of that impact occurring over a) the next 10 years, and b) the next 50 years using Ballot software (BSP Resolver Version 7.2.0.20). Participants rated impact as either *Extreme, Very High, Medium, Low,* or *Negligible* based on set scoring criteria that described conditions that the various levels of impact would cause for the Department (Appendix 8). The probability of the impact occurring at 10 and 50 year time scales was assessed as *Almost Certain, Likely, Moderate, Unlikely,* or *Rare* (Appendix 8). The reader should note that the definitions of impact and probability used here are different from the more familiar Intergovernmental Panel on Climate Change (IPCC) definitions. Participants used a scale of percent probability to gauge differences among categories of probability when voting. This scale was translated to a probability range to be displayed on heat maps. The impact was assumed to be the same on both time horizons and as such, impact voting was conducted only once per risk. Only the probability of occurrence changed between the 10 and 50 year timeframes. Voting was anonymous.

There were six sets of results, one for each of the six identified Departmental risks. Review of voting results occurred in plenary. Participants discussed results, and in cases where there was a significant lack of agreement, they repeated the vote. Results assumed independence of impact and probability.

Participants noted a number of assumptions prior to evaluating risk:

- The assessment was based on the best understanding of the science currently available to participants at the time of this meeting.
- There will be no new risk mitigation between now and 10 or 50 years.
- There is inherent spatial and/or temporal variability in several of the risk drivers.
- The assessment of the non-biological risks (Risks 4-6) was conducted with limited contribution from technical experts.

Individual Risk Voting Results

The participants, as representative of the group and its level of expertise, accepted voting results for each Risk. There was one occasion where a second vote occurred after some discussion (Risk 5, see below).

The majority of participants assessed that impact of the biologically oriented risks (Risks 1, 2 and 3) to the Department was ‘very high’ (Fig. 2). Risk drivers associated with these risk categories included almost all TP drivers (Appendix 1).

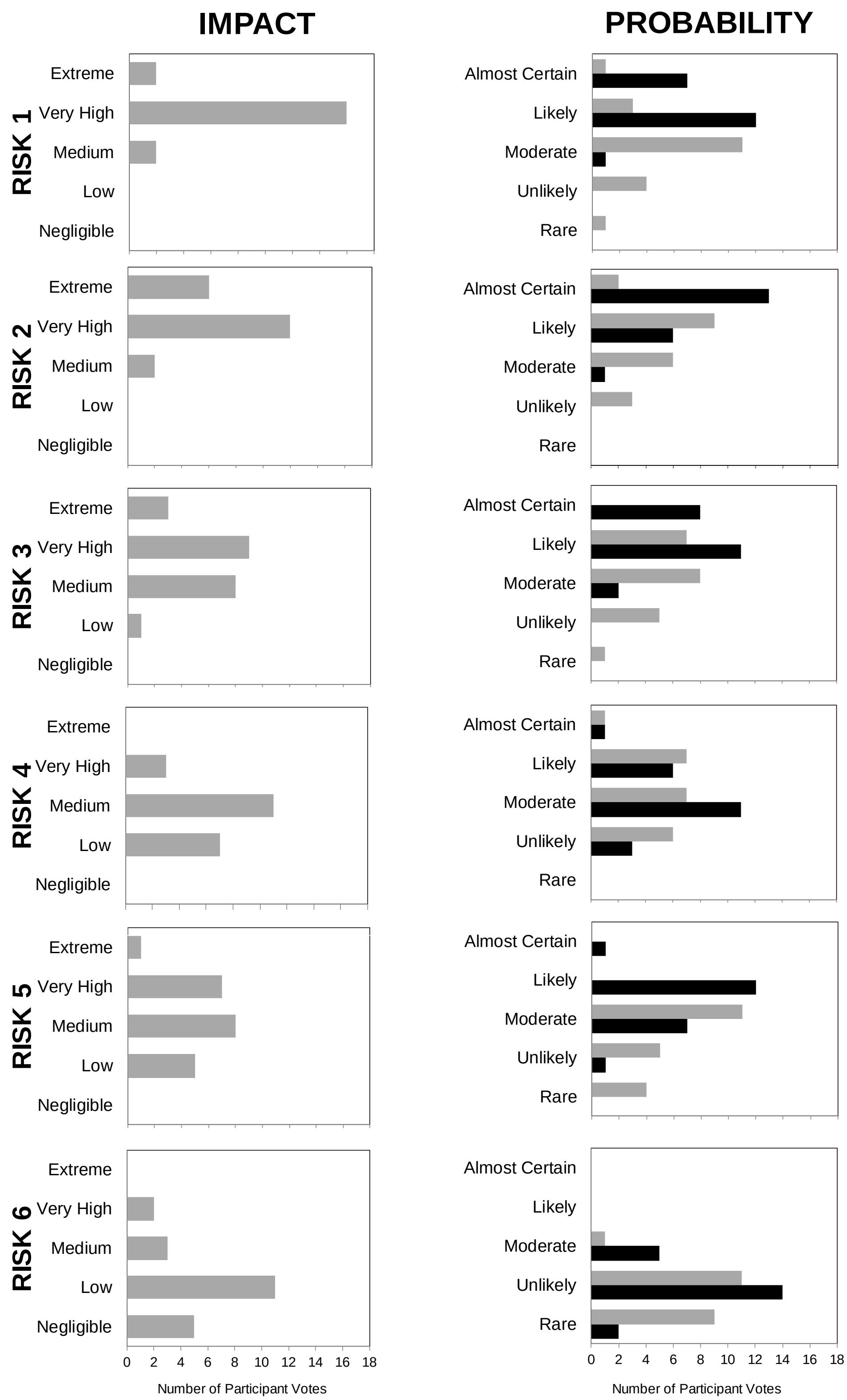


Figure 2. Results of Impact and Probability ranking by participants during the meeting using the criteria from Appendix 8. For the Probability, the grey bars indicate the Probability on a 10 year timeframe, and the black bars on a 50 year timeframe. Voting sample size were n=20 and n=21 for Risks 1-2 and Risks 3-6 respectively.

The probability that the assessed impact of biological risks will occur in 10 and 50 years was different between time horizons, and some slight differences emerged between the biological risks (Risk 1, 2 and 3). For the 10 year assessment, probability across the three risks showed a wider spread in responses, though ‘moderate’ and ‘likely’ were the most common responses (Fig. 2). Probability at 50 years centered on ‘likely’ and ‘almost certain’ (Fig. 2).

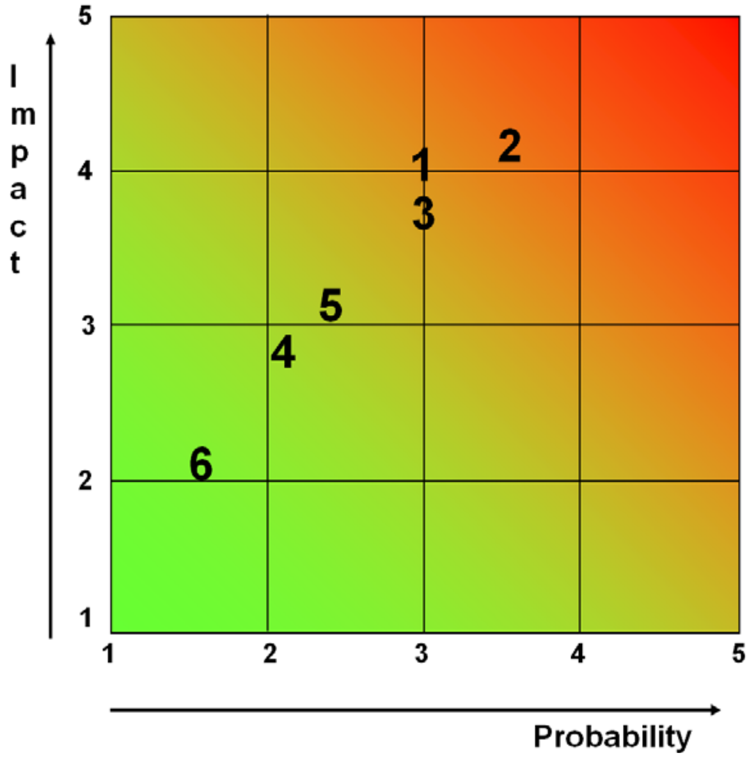
For the risk categories associated with infrastructure elements (Risks 4-6), voting on impact showed that participants assessed that the impact of these risks to the department to be lower than the impacts of biological elements. Participants assessed the impact of increased demand to provide emergency response and of infrastructure damage (Risk 4 and 5 respectively) as ‘medium’, and the impact of changes in access and navigability (Risk 6) as ‘low’.

Votes on probability of impact to infrastructure (Risks 4, 5 and 6; Fig. 2) showed there was ‘likely’ to ‘moderate’ probability for both periods. The vote on the probability of infrastructure damage (Risk 5) underwent a second vote after CCG participants raised a concern that the initial voting outcome was inconsistent with their knowledge. Participants were informed that Fraser River light stations, in particular, were already experiencing consequences associated with Risk 5, and CCG expertise suggested that these impacts will continue to occur and will increase on short time frame. A revote after discussion resulted in mildly altered results, but remained a ‘moderate’ probability at 10 years. At 50 years, participants assessed probability of Risk 5 to be ‘likely’. ‘Unlikely’ was the overwhelming response for probability of change in access and navigability of waterways (Risk 6) for both 10 and 50 year periods.

Risk Heat Maps

Using Ballot software, we prepared Heat Maps to analyse voting results. These plot the perceived impact of each Risk against the estimated probability of the impact occurring at 10 and 50 year timescales (Figs. 3 and 4).

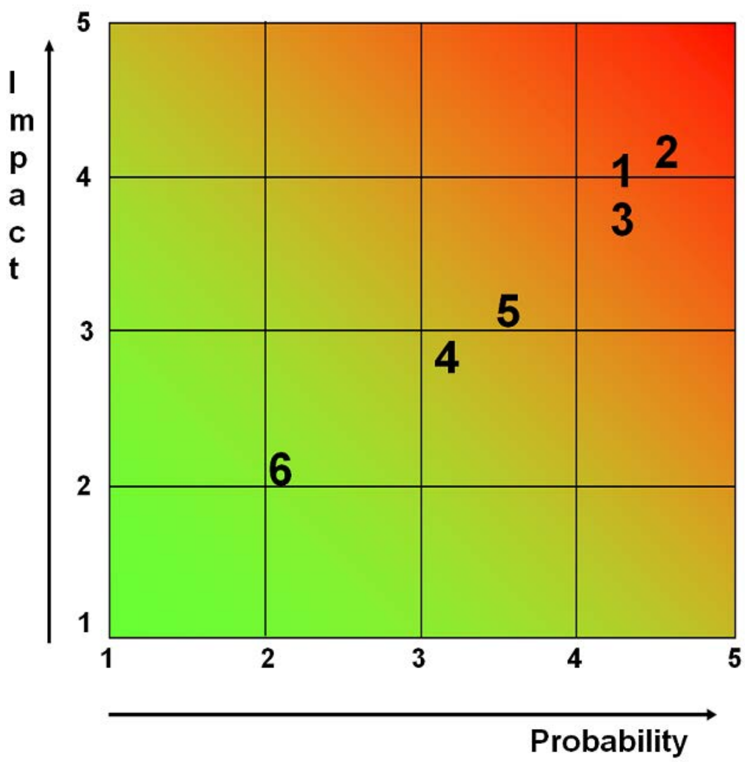
Overall, participants ranked risk to biological elements higher than infrastructure elements. They ranked Risk 2, changes in biological resources, as having the greatest risk exposure, i.e., the greatest impact and probability of occurrence for the Department for both timescales (Figs. 3 and 4). The assessment revealed that ecosystem and fisheries degradation and damage (Risk 1) and species reorganization and displacement (Risk 3) are at higher risk relative to the other risks. Participants assigned the lowest risk exposure assigned over both timescales to Risk 6, change in access to navigable waterways. Of the infrastructure risk categories, infrastructure damage (Risk 5) showed the greatest risk to the Department. Heat maps showed that for all risk categories, the probability increased from the 10 to 50 year time scale (Figs. 3 and 4).



Six Departmental 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 3. Heat map showing the impact to the Department verses the probability of occurrence for each of the six Departmental risks for the 10 year timescale in the PLAB. See Appendix 8 for ranking criteria.



Six Departmental 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
1) 6) Changes in Access and Navigability of Waterways

Figure 4. Heat map showing the impact to the Department verses the probability of occurrence for each of the six Departmental risks for the 50 year timescale in the PLAB. See Appendix 8 for ranking criteria.

Consequences and opportunities identified for the Department

The review of Risk Summary Sheets by participants included the identification and clarification of several consequences and opportunities associated with projected climate change in the Pacific LAB (Appendix 2-7). Table 2 outlines some of the consequences to biological and infrastructure risk categories.

Table 2. Abbreviated list of consequences and opportunities identified for the biological risks (risks 1-3) and hard infrastructure risks (risks 4-6).

	Consequences	Opportunities
Biological Risks	- Altered productivity due to changes in trophic interactions and critical habitat. - Spatially dependent reduction in abundance caused by changes in recruitment and growth. - Altered distribution or availability of habitat. - Altered distribution and/or abundance of marine organisms. - Reorganization of species assemblages as species interact with shifting conditions at different rates.	- Possible increases in yield of several important commercial species.. - Possible improved use of key species used in aquaculture (invertebrates) due to suitable habitat expansion. - - Potential alleviation of parasite prevalence in near shore areas.
Hard Infrastructure Risks	- Restricted use, reallocation of search and rescue resources leading to lowered ability to respond. - Relocation of facilities - Inadequate or ineffective infrastructure capital. - Disruption of navigation.	- Opportunity to work with other Departments to improve climate predictability and projections. - Potential to improve access or navigability in some areas.

Gaps in Knowledge

This process did not achieve a full exploration or documentation of gaps in knowledge associated with climate change impacts. Participants captured broad gaps that identified, in many cases, very significant gaps in knowledge, resources, observations, and capacity of current models to project future change at the LAB scale. A virtual lack of knowledge of climate drivers and ecosystem components across some sub-basins of the Pacific LAB (e.g. Gulf of Alaska, PNC) and adjacent freshwater systems contributes to significant unknowns in this LAB. There is a weakened ability in the Department to adapt to climate change given such fundamental gaps.

Gaps in knowledge presented here reveal that the Department is vulnerable to the effects of climate change beyond what the risk assessment itself establishes. The focus of this exercise was on the development of conceptual pathways that explore impacts of future climate change on DFO’s mandate. The assessment did not allow consideration of cumulative interaction of climate drivers or the interaction of multiple drivers on ecosystems or infrastructure. Participants did not address uncertainty associated with accepted risk drivers, nor did they assess variation in uncertainty among risk drivers when casting votes due to the design of the assessment. The discussion of Risk 7 advised that the Department might propose to investigate risks to the management processes and decision-making tools used to manage climate change impacts. Participants emphasized that research focusing on climate change impacts on biological resources and infrastructure will continue to reveal further gaps in knowledge.

Last, a fusion of risk across geographic components of Pacific LAB (freshwater and marine) is not recommended in future risk assessments because there is substantive contrast in climate drivers and impacts in these environments that are masked by the current analysis. Further, differences among sub-basins and the need for local adaptation solutions will likely become apparent as ACCASP proceeds.

Next steps/ recommendations

This assessment produced high-level information on the expected impacts of climate change on some aspects of ecosystems, species and infrastructure that fall under the purview of DFO. However, to make sound risk-management and adaptation decisions, the Department must align the projected spatial variability of climate change drivers and ecosystem impacts with the distribution of resources and infrastructure managed by the Department. Participants recommended that assessments of risk at finer resolutions occur in the future, where sufficient information is available.

Further development of regional models to downscale information from climate projections generated with global models will be essential to managing the wide array of climate impacts that are likely to affect Departmental operations in Pacific LAB.

Conclusions

Trends and Projections (TP) and Impact, Vulnerabilities and Opportunities (IVO) information informed the risk assessment for Pacific LAB as a whole.

Participants reviewed all of the climate trends and projections and risk summary sheets including risk drivers. Follow-up assessments might use an inventory approach (not a literature survey) to identify and establish regional impacts, vulnerabilities, opportunities and gaps. Participants suggested a refinement of the definitions and context of each Risk to build on themes and gaps offered by this LAB-based assessment. To that end, Pacific LAB suggests committing to a review of climate change risks to soft infrastructure elements that fall under the purview of DFO.

The results of this meeting suggest that biological associated impacts from climate change in the Pacific LAB pose the greatest risks to the Department, specifically ecosystem degradation and damage. Results from this assessment will inform the upcoming departmental integrated climate change risk assessment. This integrated approach will allow a prioritization of risks from a wider perspective of the Department's activities. ACCASP's risk assessment is an iterative process. Therefore information from planned integrated sector meetings, formalized regional TP and IVO documents and increased participation at additional Science advisory risk assessment meetings by other scientific and technical experts (i.e., increased sample size for voting, broadened expertise and experience) will increase the confidence of the assessments.

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Appendix 1

Trends and Projections summary table for the Pacific LAB.

Atmospheric Processes and Precipitation

Risk Factors (variables)	Trends in past conditions[1]	Climate projections over next 50 years
Air Temperature	Annual mean air temperature has increased at a rate of ~0.1 °C / decade, with greater increases in winter, in the SOG and WCVI[2] sub-basins. In the PNC sub-basin the rate of increase is 0.1-0.15 °C /decade in winter and spring and negligible in summer.	An annual air temperature increase of 1-3°C is projected for coastal regions, with winter temperatures at the high end of this range and summer temperatures near the low end. Open ocean regions offshore expect an annual mean increase of ~3°C. Interior continental temperatures affecting freshwater ecosystems will warm 3-5°C.
Precipitation	In the SOG and WCVI subregions annual precipitation has increased by 25-50% since 1930, with the largest increases in winter and spring. In the PNC sub-basin the increase is slightly smaller and occurs predominantly in winter.	The warmer atmosphere leads to increased precipitation globally, but increasing summer drought over land. Over land, more precipitation will fall as rain rather than snow, leading to a slightly earlier peak spring runoff. Projections are for increased precipitation in winter and less in summer for most coastal regions. Precipitation over open ocean waters should see a slight increase.
Upwelling winds	Winds along the British Columbia outer coast are upwelling-favourable in summer and downwelling-favourable in winter. The recent trend in the WCVI region is for stronger downwelling winter winds and a shorter summer upwelling season, but with slightly stronger winds. For the PNC sub-basin the trend is similar but without the intensified wind in summer. In the SOG winds appear to have decreased slightly over the late 20th century.	Winds along the British Columbia outer coast are upwelling-favourable in summer and downwelling-favourable in winter. Projections are for slightly stronger winds in both summer and winter (WCVI), or for downwelling winter winds and summer upwelling winds of similar strength but slightly reduced duration (PNC). No robust projection information is available for GOA or SOG.
Streamflow	Time of peak Fraser River flow is moving forward by about 10 days/century while total annual flow remains about the same. Summer river temperatures are increasing by about 1.2°C/century.	Streamflow is expected to be ~10% lower in June-August and 10% higher at other times of the year in the SOG. Seasonal pattern is similar in other coastal sub basins, but summer reduction is less.

Water and Sediments

Risk Factors (variables)	Trends in past conditions[1]	Climate projections over next 50 years
Water temperature	In the open waters of the GOA, the recent trend has been for warming at a rate up to 1°C/century at the surface, declining to zero at 500 m depth. In coastal regions, surface temperatures are increasing at 0.51 ± 0.72 °C/century at Kains Island and 1.39 ±0.52 °C/century at Entrance Island.	Sea surface temperature is expected to increase by 1.5-2°C, except in summer in WCVI where increased upwelling will reduce the overall warming by about half. Less warming is projected in lower layers.
Sea surface salinity (ppt)	In the open waters of the GOA, the recent trend has been for freshening (decrease salinity) at a rate up to 0.2 ppt/century at the surface, declining to zero at 100 m depth. In coastal regions, surface salinity trends are -0.47 ± 0.49 ppt /century at Kains Island and -0.76 ± 0.53 ppt /century.	Sea surface salinity (SSS) will decline by 0.25-0.3 ppt in GOA and by up to 1 in coastal subbasins, but there is considerable seasonal variation. In SOG summer SSS may increase by up to 0.5 ppt due to reduced precipitation and runoff; in WCVI it will increase in winter due to increased downwelling-favourable winds and and narrowing of the relatively fresh Vancouver Island Coastal Current. In PNC it will likely decrease by ~1 ppt in summer/fall with no appreciable change in winter/spring.
Stratification	In the open waters of the GOA the recent trend has been towards greater stratification, with the density difference between surface and subsurface waters increasing at up to 0.5 kg/m^3/century.	Greater stratification in Juan de Fuca Strait in spring and summer, and in the open waters of the Gulf of Alaska. Mixed layer depth may increase slightly off the west coast of Haida Gwaii in PNC. Changes in lake stratification have been observed at temperate and high latitudes lakes and are anticipated to continue.
Currents	In the open waters of the GOA there is no evidence of systematic changes in circulation.	Vancouver Island Coast Current is narrower, deeper, stronger most seasons. Surface currents may be stronger in Juan de Fuca Strait in summer. Haida eddies may increase in strength and coherence, and possibly in number.
Sea and lake level variations	Sea level has risen by 3.1 cm at Victoria and 2.0 cm at Vancouver over the past 50 years. At Tofino sea level has declined by 8.4 cm over the same period, while at Prince Rupert it has risen 10 cm in 77 years. Local deviations of sea level rise from the global mean are likely to be small except where they are associated with isostatic motion of the land, which is likely the case in many areas of British Columbia.	Local deviations of sea level rise from the global mean are highly uncertain and if they occurs are likely to be small (< 5 cm). Global mean increase is projected to be ~30 cm. This is a lower limit because it does not take account of accelerating loss of glacier mass; the upper limit could be substantially higher. Changes in lake water budgets (evaporation, evapotranspiration, glacial melt water, snowpack) are anticipated to produce changes in seasonal lake elevation.

Risk Factors (variables)	Trends in past conditions[1]	Climate projections over next 50 years
Acidification	Recent trends from other locations suggest a downward trend in surface pH of about 0.0017/yr and in aragonite saturation of 0.007/yr. Deviations from the global mean are expected to be small at the surface but could be significant in the thermocline. Data records from Line P Program sampling are short due to early problems with alkalinity but current and ongoing trends are being monitored.	Surface ocean pH declines by 0.13, and aragonite saturation declines by 0.29 at the 1026.6 kg m^3 density surface. This isopycnal (i.e. water surface that is constantly at 1026.6 kg m^3 density) was chosen to be representative of the main thermocline of the Gulf of Alaska, and represents waters that potentially impact the British Columbia continental shelf. The surface pH trend should be close to the global mean for open ocean waters, but local deviations from the global trend in coastal waters are not yet known.
Oxygen concentration	In the coastal subregions, oxygen concentration declined by ~0.5 μmol/kg/yr from 1960-2012. In the open waters of the Gulf of Alaska a similar rate of decline is observed in the 1026.3-1027.0 kg m^3 density range (about 100-400 m depth).	Oxygen concentration will decline by ~36 μmol/kg at the 1026.6 kg m^3 density surface in the open waters of the Gulf of Alaska. Deep water oxygen depletion in lakes is expected to become more frequent in certain areas.
Nutrients	In the open waters of the Gulf of Alaska there is a weak trend of increasing thermocline nitrate concentration, of about 0.13 μmol/kg/yr at 150 m depth (1956-2011).	No significant change in surface nitrate concentration is projected in the Gulf of Alaska. In freshwater ecosystems, changes in delivery of limiting nutrients are anticipated.

[1]Definitions as provided by Pacific ACCASP Trends and Projections Group

A trend is based on past observations, and the length of the observational records varies. A projection is estimated from climate model output based on assumptions about future anthropogenic greenhouse gas emissions. We make projections only for the 50 year timescale due to some unique features of North Pacific climate as described below.

Because in the North Pacific interannual to interdecadal climate variability is large relative to secular trends, climate model projections have no predictive skill on the 10-year time scale, and trends based on less than 20-30 years of data cannot be assumed to represent longer term trends.

So 10-year projections are best estimated as linear extrapolations of past trends, with the caveats that (a) only those based on relatively long time series are robust trends, and (b) even these are only our best estimate of the long-term secular trend on which unpredictable shorter term variability is superimposed, and not the total signal.

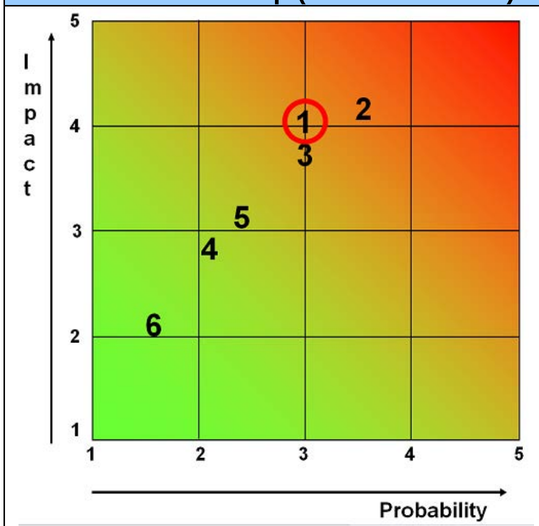
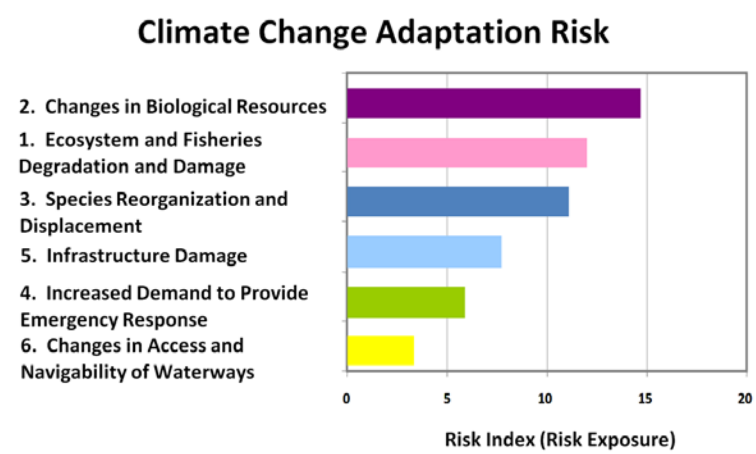
[2]Codes

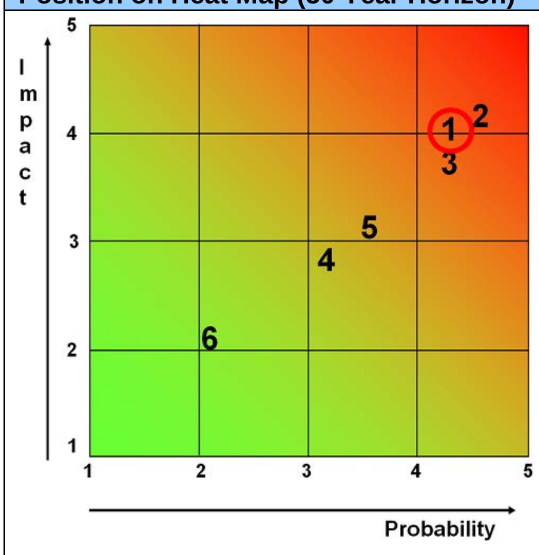
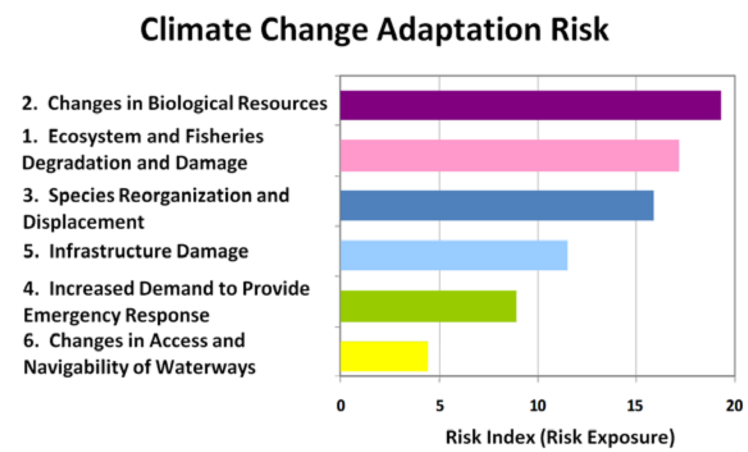
GOA = Gulf of Alaska
PNC = Pacific North Coast
SOG = Strait of Georgia
WCVI = West Coast Vancouver Island

Appendix 2

Risk summary sheet for the Ecosystem and Fisheries Degradation and Damage (Risk 1) for the Pacific LAB. Each grouping of main risk drivers (left column) align with the grouping of potential opportunities- consequences (right column).

Pacific 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) Impacts on Bioenergetics/ Physiology Projected increases in **marine and freshwater temperatures** will have consequences for Pacific fish species through differences in mortality or through alterations to growth and reproduction. Changes in **environmental conditions (e.g. warmer temperature and ocean upwelling conditions)** alter the community structure because the physiology and energetics of species will match habitat conditions. Changes to **wind strength** and **ocean temperature and salinity** that influence marine currents may lead to altered circulation at the regional scale with potential impacts for the availability of nutrient rich upwelling waters and seasonal production dynamics of phytoplankton and zooplankton Projected decreases in **ocean pH** will affect species that incorporate calcium carbonate into skeletal/shell structures.	**1) Impacts on Bioenergetics/ Physiology** **Reduced ability to predict abundance of fishery resources.** Climate change will interact with existing stressors. **Pacific salmon:** Possible reduction in salmon abundance, especially where freshwater survival is negatively impacted. Cumulative effects on survival may be sufficient to extirpate populations within Conservation Units (CUs) from the most affected areas. **Groundfish:** Long-term changes to the availability of preferred thermal habitats for various life stages of species, and to growth, age at maturity and fecundity. **Small Pelagics:** Potential reduction in abundance of some pelagic species (i.e. herring in some areas). **Lower Trophic Levels:** Smaller, less energy-rich prey species are associated with warmer ocean conditions (or stronger/weaker upwelling events) that originate in southern, warmer waters. Food webs based on small-sized plankton are not as productive because the energy flow to upper trophic levels is not as efficient. Altered productivity of invertebrates and fishes associated with impacts of decreased pH in the ocean.
2) Distribution and Abundance **Warming** will contribute to shifts in the distribution of species via changes in recruitment, growth, survival and migration patterns of planktonic and adult life stages. Changes in **precipitation** that lead to increased freshwater discharge of freshwater may alter stratification of estuaries and coastal areas. Changes in **stratification** may result in community responses that favour more euryhaline (tolerant of variation in salinity) and anadromous fish species over	**2) Distribution and Abundance** **ALL SPECIES** Species ranges will shift poleward at different rates. There may be reorganization of assemblages that result in the greater separation or overlap of species distributions. **Pacific salmon:** Cumulative interactions among climate regimes and salmon dynamics in freshwater and marine ecosystems will likely result in a northward expansion of all species

Main Risk Drivers	Potential Consequences: Threats
marine species. Establishment and enlargement of areas of **low dissolved oxygen at depth** will have effects on the distribution of benthic and demersal species. Changes to **circulation, stratification and upwelling** will potentially impact the availability of nutrient rich upwelling waters and abundance and community composition of phytoplankton and zooplankton. **Freshwater discharge (precipitation + glacial melt)** is expected to increase for coastal areas (except for summer months when it will decline) impacting the spatial pattern of plankton productivity. **Increase in freshwater temperature** in watersheds will impact the distribution and abundance of fish and invertebrates. **Ocean acidification** will likely be most severe in coastal upwelling regions and in deeper strata.	along with reduced productivity for populations on the southern end of their range. Climate induced displacement of seasonal rearing and overwintering areas to the north (e.g. GOA, Bering Sea) with generally unknown production consequences. **Small pelagics:** Extension and/or shrinkage of geographic distribution of species will occur as a result of changes in lifespan and reproductive rates linked to temperature. **Benthic and demersal species:** Dissolved oxygen is known to be lower in terminal marine inlets, many of which are already hypoxic. These conditions reduce available habitat for fish and can result in fish-kills. Reorganization of ecosystems, requiring new management systems, recovery strategies for species and shifts in regional management priorities. Our ability to define ecologically important areas (e.g., Ecologically and Biologically Significant Areas) for Marine Protected Areas, fisheries or other management tools may be affected. **Invertebrates:** Variations in abundance of pink shrimp off WCVI are correlated with changes in water temperature occurring two years prior to their natal year; abundance decreases in warm water periods and increases in cold water periods. **Transient species:** Occasional irruptions of southern predatory species (e.g., Humboldt squid, Pacific mackerel), may impact valuable commercial marine species through competition or direct predation. Increased incidence and prevalence of nuisance species (i.e. jellyfishes) may increase in association with increasing water temperature and hypoxia. **Marine Mammals:** Changes in trophic structure and species distributions will alter bio-magnification of contaminants, including persistent organic pollutants and mercury, and

<table>
<tr><th>Main Risk Drivers</th><th>Potential Consequences: Threats</th></tr>
<tr><td></td><td>potentially affect top-level predatory fish and marine mammals, including whales and pinnipeds.</td></tr>
<tr><td>3) Phenology (Timing Mis-Match)

Changes in phenology that is linked to water temperature increase, onset of ocean upwelling, freshwater discharge and wind intensity can cause a timing mis-match of prey resources at critical life stages and timing of moulting periods that affect survival and abundance.</td><td>3) Phenology (Timing Mis-Match)

Changes in zooplankton availability may favour species with spring vs summer larval periods (some winners, some losers).

Pacific salmon: Possible decrease in survival may occur where changes affect hatching and emergence timing, earlier smolt migration to the ocean, early or late returns to harvest areas and homing river, and delays in spawning migration.

Groundfish and Small pelagics: Earlier marine zooplankton seasonal timing is linked to lower survival of some species (i.e. rockfish, sablefish,).

Invertebrates: Species interactions, feeding and movement behaviour that relate to stages of moulting may also be disrupted with unknown consequences.

Lower Trophic Levels: Changes in phenology may contribute to biomass declines of large energy rich zooplankton species that are important forage food items for many predators.

Marine Mammals: Specialist predator species have preference for a few key prey items, suggesting that any significant change to spatial or temporal overlaps of predator and prey may impact predator populations negatively.</td></tr>
</table>

Opportunities
▪ Some important invertebrate commercial species (crab, prawn, geoduck) may be impacted positively by warming conditions. ▪ Possible increases in yield of one or more salmon species. ▪ Possible increase in the commercial importance of migratory hake, Pacific mackerel, sardine and albacore tuna.

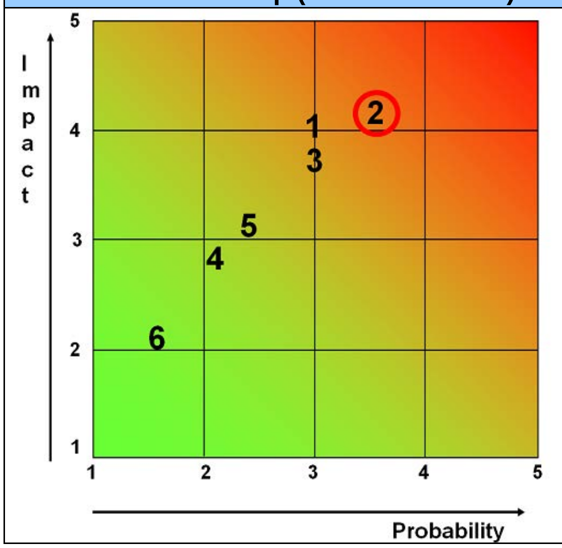
Gaps
▪ There is limited understanding of the consequences to the management decision making process caused by the effects of climate change on migration, alterations in production and changes in stock-recruitment relationships. ▪ There is limited understanding of the effects of changes in spatial distributions and abundance of key species on regional productivity. ▪ There is a need for greater capacity to predict environmental changes and ecosystem responses at sub-basin scales, including the development of regional biogeochemical, coupled-physical and downscaling models. ▪ There is a need for greater capacity in predicting shifts in the timing of environmental drivers and in determining their consequences to the phenology, adaptation and productivity of key freshwater and marine species. ▪ There is a gap in our understanding of how to incorporate cumulative effects into assessment (risk, vulnerability, etc.) processes. ▪ The lack of data and knowledge of some key regions, in particular in the PNC and GOA sub-basins, limits opportunities to understand and mitigate impacts of climate change. ▪ There is a need for reliable and continuous time-series of observations (biological and oceanographic). ▪ Open ocean subsurface waters of the subarctic Pacific have extremely low oxygen concentrations and calcium carbonate saturation states. Future trends in these properties and their transport onto the continental shelves are poorly understood. In coastal waters modulation of ocean acidification by freshwater inputs and interaction with the sediments are poorly understood. ▪ Our ability to predict the impacts of climate change on freshwater networks and their consequences to anadromous fish are limited. These environmental conditions are soon likely to be outside the range of historical variability. ▪ The limited information on near shore environments translates into a lack of knowledge of climate-habitat interactions and resulting impacts on fish and invertebrates using these areas for important life stages. ▪ Extreme events in freshwater systems (droughts and floods) may be influential but need to be investigated.

Appendix 3

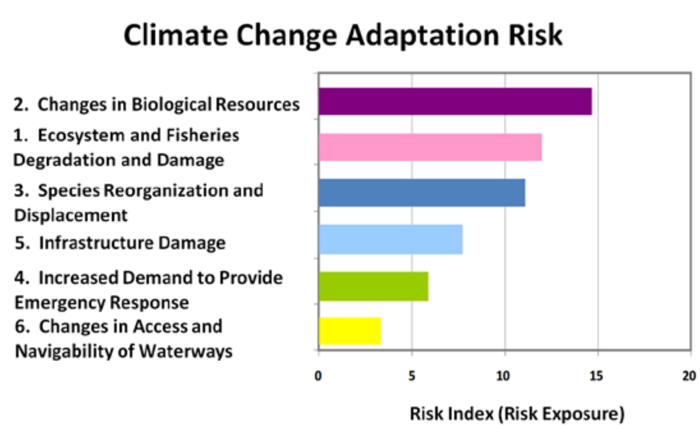
Risk summary sheet for the Changes in Biological Resources (Risk 2) for the Pacific LAB. Each grouping of main risk drivers (left column) align with the grouping of potential opportunities- consequences (right column).

Pacific 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’s Act).

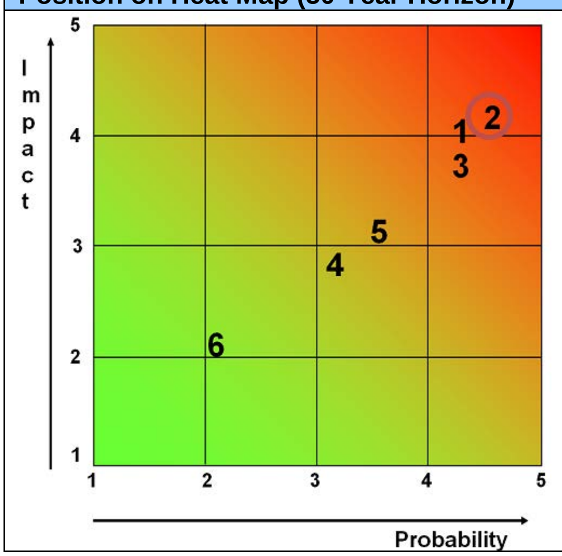
Position on Heat Map (10 Year Horizon)



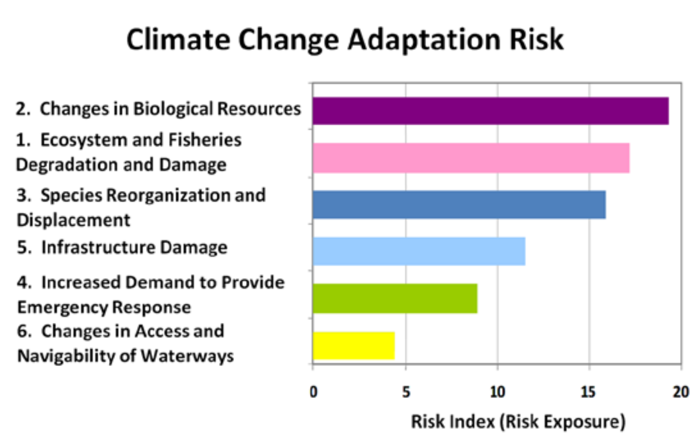
Risk Index (Probability x Impact)(10 Year Horizon)



Position on Heat Map (50 Year Horizon)



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



Main Risk Drivers	Potential Consequences: Threats
1) Impacts on Bioenergetics/ Physiology Projected increases in **marine and freshwater temperatures** will have consequences for Pacific fish species through direct mortality or indirectly through alterations to growth and reproduction. Changes in **environmental conditions (e.g. warmer temperature, oxygen concentrations and ocean upwelling conditions)** alter the community structure and function because the physiology and energetics of species will match habitat conditions. Changes to **wind strength** and **ocean temperature and salinity** that influence marine currents may lead to altered circulation at the regional scale with potential impacts for the availability of nutrient rich upwelling waters and seasonal production dynamics of phytoplankton and zooplankton **Freshwater temperature and discharge** that affect migration of anadromous species downstream and upstream with have an impact mortality and yield.	**1) Impacts on Bioenergetics/ Physiology** **Reduced ability to predict abundance of fishery resources** **Pacific salmon:** Possible reduction in salmon abundance, especially where freshwater survival is negatively impacted. Cumulative effects on survival may be sufficient to extirpate populations within Conservation Units (CUs) from the most affected areas. **Groundfish:** Long-term changes to the availability of preferred thermal habitats for various life stages of species, and to growth, age at maturity and fecundity. **Small Pelagics:** Potential reduction in abundance of some pelagic species (i.e. herring in some areas). **Lower Trophic Levels:** Smaller, less energy-rich prey species are associated with warmer ocean conditions (or stronger/weaker upwelling events) that originate in southern, warmer waters. Food webs based on small-sized plankton are not as productive because the energy flow to upper trophic levels is not as efficient. Altered productivity of invertebrates and fishes associated with impacts of decreased pH in the ocean.
2) Distribution and Abundance **Warming** will contribute to shifts in the distribution of species via changes in recruitment, growth, survival and migration patterns of planktonic and adult life stages. Changes in **precipitation** that lead to increased freshwater discharge of freshwater may alter stratification of estuaries and coastal areas. Changes in **stratification** may result in community responses that favour more euryhaline (tolerant of variation in salinity) and anadromous fish species over marine species. Establishment and enlargement of areas of	**2) Distribution and Abundance** **ALL SPECIES** Species ranges will shift poleward at different rates. There may be reorganization of assemblages that result in the greater separation or overlap of species distributions. **Pacific salmon:** Cumulative interactions among climate regimes and salmon dynamics in freshwater and marine ecosystems will likely result in a northward expansion of all species along with reduced productivity for populations on the southern end of their range.

Main Risk Drivers	Potential Consequences: Threats
low dissolved oxygen at depth will have effects on the distribution of benthic and demersal species. Changes to **circulation, stratification and upwelling** will potentialy impact the availability of nutrient rich upwelling waters and abundance and community composition of phytoplankton and zooplankton. **Freshwater discharge (precipitation + glacial melt)** is expected to increase for coastal areas (except for summer months when it will decline) impacting the spatial pattern of plankton productivity. **Increase in freshwater water temperature** in watersheds will impact the distribution and abundance of fish and invertebrates.	Climate induced displacement of seasonal rearing and overwintering areas to the north (e.g. GOA, Bering Sea) with generally unknown production consequences. **Small pelagics:** Extension and/or shrinkage of geographic distribution of species will occur as a result of changes in lifespan and reproductive rate linked to temperature. **Benthic and demersal species:** Dissolved oxygen is known to be lower in terminal marine inlets, many of which are already hypoxic. These conditions reduce available habitat for fish and can result in fish-kills. Reorganization of ecosystems, requiring new management systems, recovery strategies for species and shifts in regional management priorities. (Risk 7?) Our ability to define ecologically important areas (e.g., Ecologically and Biologically Significant Areas) for Marine Protected Areas, fisheries or other management tools may be affected. **Invertebrates**: Variations in abundance of pink shrimp off WCVI are correlated with changes in water temperature occurring two years prior to their natal year; abundance decreases in warm water periods and increases in cold water periods. **Transient species:** Occasional irruptions of southern predatory species (e.g., Humboldt squid, Pacific mackerel), may impact valuable commercial marine species through competition or direct predation. Increased incidence and prevalence of nuisance species (i.e. jellyfishes,) may increase in association with increasing water temperature and sea-level rise, and acidification. Altered production dynamics at the base of the food chain will likely impact resident fishes off the British Columbia coast.

<table>
<tr><th>Main Risk Drivers</th><th>Potential Consequences: Threats</th></tr>
<tr><td>3) Phenology (Timing mis-match)

Changes in phenology that is linked to water temperature increase, onset of ocean upwelling, freshwater discharge and wind intensity can cause a timing mis-match of prey resources at critical life stages and timing of moulting periods that affect survival and abundance.</td><td>3) Phenology (Timing mis-match)

Changes in zooplankton availability may favour species with spring vs summer larval periods (some winners, some losers).

Pacific salmon: Possible decrease in survival may occur where changes affect hatching and emergence timing, earlier smolt migration to the ocean, early or late returns to harvest areas and homing river, and delays in spawning migration.

Groundfish and Small pelagics: Earlier marine zooplankton seasonal timing is linked to lower survival of some species (i.e. rockfish, sablefish).

Invertebrates: Species interactions, feeding and movement behaviour that relate to stages of moulting may also be disrupted with unknown consequences.

Lower Trophic Levels: Changes in phenology may contribute to biomass declines of large energy rich zooplankton species that are important forage food items for many predators.</td></tr>
<tr><td>4) Aquaculture

Warming may contribute to a reduction in biological performance (e.g. growth) of species (finfish and invertebrates) through changes in primary productivity (food supply) and increased abundance of non-native and native fouling organisms.

The effects of ocean acidification may reduce productivity of cultured invertebrate species.

Changes in environmental conditions (temperature and salinity) may affect the incidence and/or prevalence of parasites, pests and pathogens that impact finfish and invertebrate species.

Exposure of shoreline to sea level rise and storm surges may change shoreline configurations in low-lying areas affecting areas used for production.</td><td>4) Aquaculture

Potential changes to operations and production based on changes to wild-origin fish feed availability and cost.

Increased sensitivity of finfish to harmful algal blooms as near shore temperatures increase.

Competition for space and predation by invasive species and nuisance species on invertebrates being cultured in ‘natural’ environments (i.e. beaches).

Increased management of aquaculture tenure locations, escape events, invasive species.

Increases/changes in product safety management associated with changes in pests, parasites and pathogens.

Infrastructure integrity: Intense storms can damage net pens leading to fish escapes and production losses.</td></tr>
</table>

Main Risk Drivers	Potential Consequences: Threats
	Presence of invasive fouling species in addition to native species could present further operations challenges and increased production costs (fouling management).
5) Salmon enhancement Increased water temperature (freshwater and marine) may alter production capacity of facilities and impact survival of fish.	**5) Salmon enhancement** Lethal/sub-lethal water temperatures combined with handling or counting stress will increase pre-spawning mortality and decrease egg and sperm viability. Emigrating smolts produced in salmon enhancement facilities released into **higher water temperature** may experience stress and physiological dysfunction resulting in possible increases in-river mortality and wider swings in marine mortality. Access to sufficient brood stock may be hindered where conflict with wild salmon escapement goals exist.

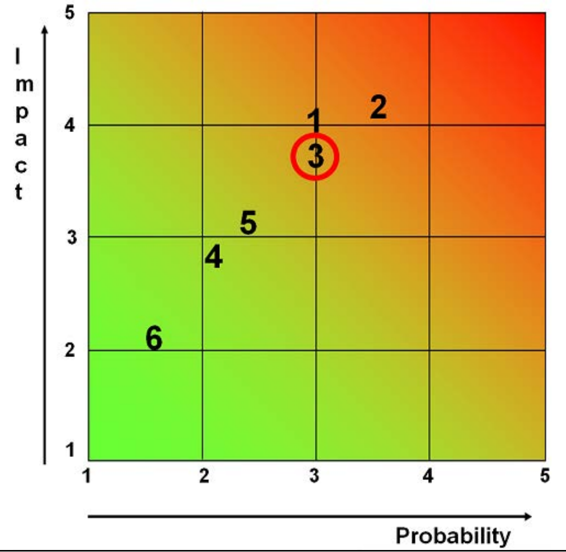
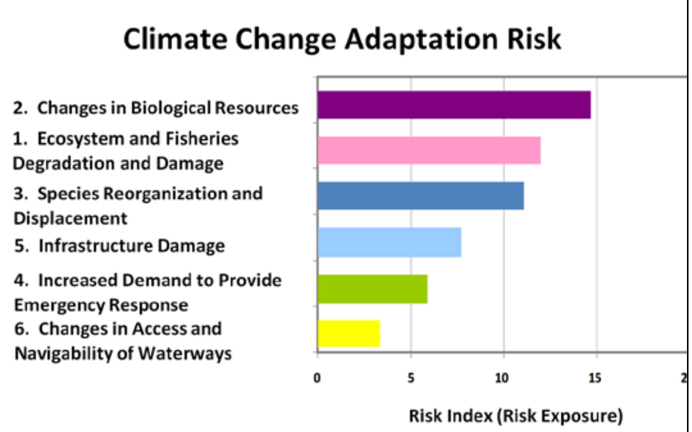
Opportunities
▪ Possible increases in squid populations, and even jellyfish may present new harvesting opportunity. ▪ Key species used in aquaculture (such as inverterbrates) that are impacted by increasing temperature may improve recruitment and expand distribution poleward. ▪ Some important invertebrate commercial species (crab, prawn, geoduck) may be impacted positively by warming trend. ▪ Possible increases in yield of one or more salmon species. ▪ Potential decrease in disease incidence and prevalence, especially in near shore areas receiving increased glacial-melt freshwater flow, as lower salinity levels may reduce sea lice abundance in coastal zones. ▪ Possible improved cultured shellfish growth through enhanced food supply.

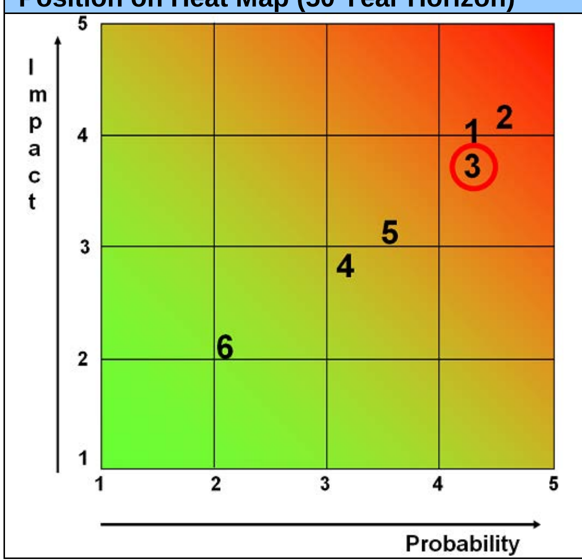
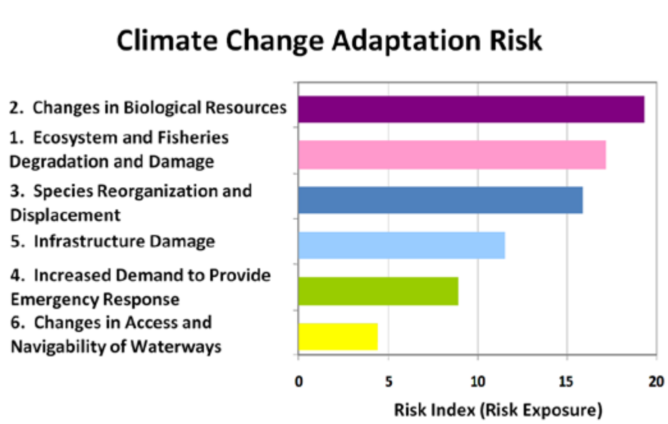
Gaps
▪ There is limited understanding of the consequences to the management decision making process caused by the effects of climate change on migration, alterations in production and changes in stock-recruitment relationships. ▪ There is limited understanding of the effects of changes in spatial distributions of key species on regional productivity. ▪ There is a need for greater capacity to predict environmental changes and ecosystem responses at sub-basin scales, including the development of regional biophysical and downscaling models. ▪ There is a need for greater capacity in predicting shifts in the timing of environmental drivers and in determining their consequences to the phenology, adaptation and productivity of key freshwater and marine species. ▪ There is a gap in our understanding of how to incorporate cumulative effects into assessment (risk, vulnerability, etc.) processes. ▪ The lack of data and knowledge of some key regions, in particular in the PNC and GOA sub-basins, limits opportunities to understand and mitigate impacts of climate change. ▪ Open ocean subsurface waters of the subarctic Pacific have extremely low oxygen concentrations and calcium carbonate saturation states. Future trends in these properties and their transport onto the continental shelves are poorly understood. In coastal waters modulation of ocean acidification by freshwater inputs and interaction with the sediments are poorly understood. ▪ Our ability to predict the impacts of climate change on varied freshwater networks and their consequences for anadromous fish (i.e. Pacific salmon) are limited throughout their range. Climate change is likely to impact mortality and survival in critical freshwater life history phases including incubation, rearing, and migration. The magnitude and variability of these environmental changes (i.e. water temperatures, altered hydrographs) will likely soon be outside of the range of historical variability. ▪ The limited information on near shore environments translates into a lack of knowledge of climate-habitat interactions and resulting impacts on fish and invertebrates using these areas for important life stages. ▪ Adjustments may be needed to operations including salmon smolt release timing including marine environmental monitoring for "good ocean conditions". ▪ Cases where salmon enhancement facilities are located in vulnerable areas need to be determined and plans should be made to revamp, relocate or close such facilities. ▪ Lack of understanding of changes in harmful algal bloom events on finfish

Appendix 4

Risk summary sheet for the Species Reorganization and Displacement (Risk 3) for the Pacific LAB. Each grouping of main risk drivers (left column) align with the grouping of potential opportunities- consequences (right column).

Pacific 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
1) Species at Risk Depleted or rare species may decline due to projected **changes in freshwater and ocean conditions** for example: anadromous species (6 listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and 2 by the Species at Risk Act (SARA)); marine fish (13 COSEWIC, 6 SARA); marine mammals (13 COSEWIC, 12 SARA); invertebrates (2 freshwater; 2 marine).	**1) Species at Risk** Possible that more species will be added to the "at risk" lists as climate change advances, putting additional strain on resources for Species at Risk management (including recovery strategies). Climatic conditions for some species at risk that are in part restricted by colder climates may improve, but the factors already limiting these species (particularly anthropogenic threats to habitat) may prevent species from capitalizing on emerging opportunities. N.B. – Warming trend may have positive impact for Olympia oysters, although increased severe weather events may have a negative impact (freezing).
2) Invasive Species Changes in **freshwater and ocean conditions** that impact species abundance and distribution and/or community structure and function could increase the likelihood of establishment of potentially invasive species. Potential expanded range of established marine invasive species as a result of changing **ocean conditions (temperature and salinity).**	**2) Invasive Species** Invasive species (e.g. green crabs) are a significant concern for management of fisheries and present a significant threat to nearshore ecosystems. N.B. – Although green crab are a serious concern, abundance and distribution are not primarily driven by changes in ocean conditions. Dispersal events beyond their current distribution may be linked to changes in currents that permit larval transport, but these have typically been ENSO events. To some extent, increased freshwater discharge and changes to salinity in estuarine environments may increase habitat available to green crabs, which have broader tolerances than many native crabs. Some non-indigenous species currently important in commercial, recreational and First Nations fisheries are considered invasive or noxious species elsewhere in the world. Some of these species have distributions limited by thermal thresholds (e.g., Manila clam, Pacific oyster); temperature increases could allow for increased dispersal and establishment of these species further poleward. The number of non-indigenous (and potentially invasive) species able to establish will increase

Main Risk Drivers	Potential Consequences: Threats
	with expected negative impacts on native community structure and function.
3) Transient species Changes in ocean conditions will allow transient species enter Canadian Pacific waters and place native species at risk.	**3) Transient species** Occasional irruptions of transient species such as the southern predatory species (e.g., Humboldt squid, Pacific mackerel), may impact species at risk through competition or direct predation.
	Biodiversity Possible that species having identified cultural value as traditional food will be lost or locally extirpated with potential outcome of legal action against the Department. Loss of biodiversity and its intrinsic value.

Opportunities
▪ Transient species: potential increases in squid, mackerel, tuna population present new harvesting opportunities. ▪ Invasive species could become commercial or recreational species. ▪ Increased water temperature may benefit production and increased distribution of some non-native cultured invertebrate species.

Gaps
▪ Management systems undeveloped for managing arrival of invasive species. ▪ Need to identify critical habitat, and linkages between these and climate change drivers.

Appendix 5

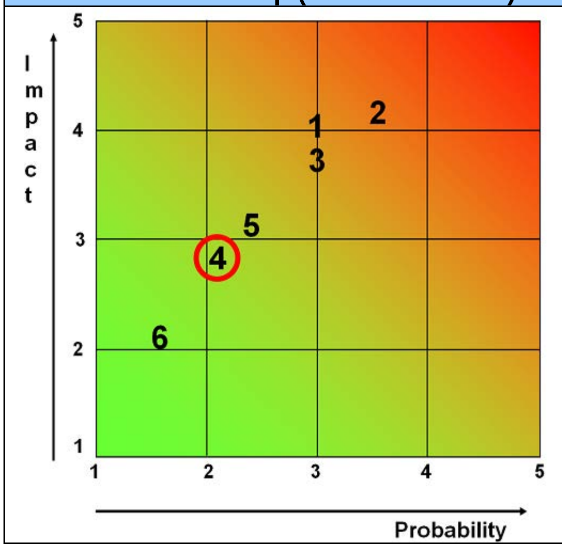
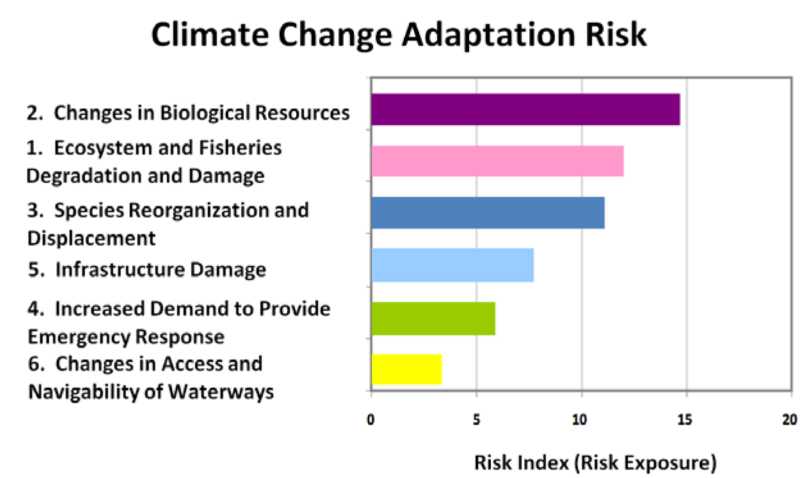
Risk summary sheet for the Increased Demand to Provide Emergency Response (Risk 4) for the Pacific LAB. Each grouping of main risk drivers (left column) align with the grouping of potential opportunities- consequences (right column).

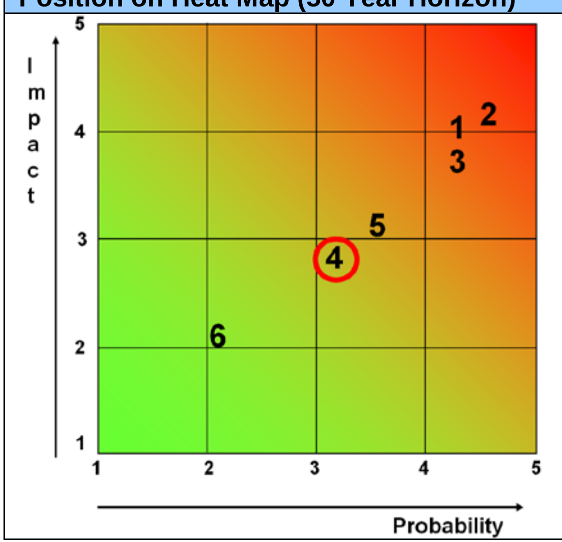
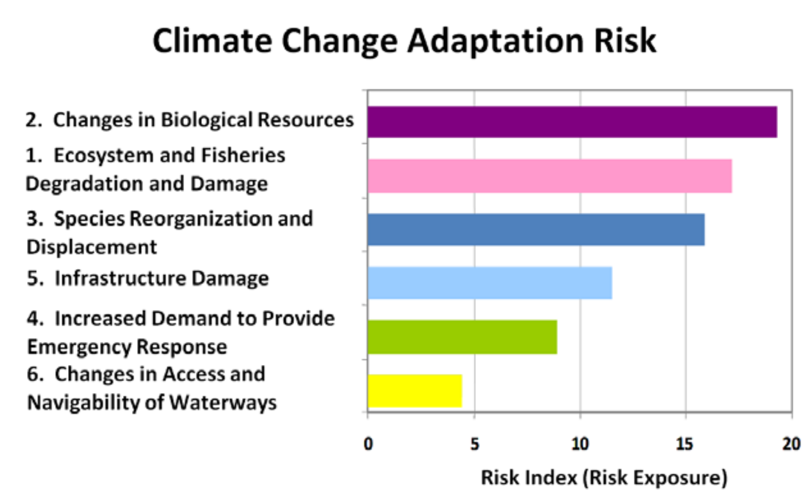
Pacific Large Aquatic Basin

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 CCG'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)
	

Main Risk Drivers	Potential Consequences: Threats
Changes in mean **sea level** may impact storm surge. **Stronger winds** and **changes in sea state** might affect Search and Rescue and environmental response activities. **Climate-driven** shifts in the distribution of fisheries effort. **Air temperature increase** may lead to potential increase in the intensity, seasonal duration and geographical extent of marine traffic (commercial and recreational).	Personnel at light stations might be at risk due to storm surges. Need for reallocation of resources (Search and Rescue needs analysis) associated with climate-driven shift in fisheries effort (commercial and recreational). Restricted use of Search and Rescue resources (e.g. small helicopter use in stormy weather) and future design of Search and Rescue response infrastructure. Lowered ability to respond to search and rescue calls and environmental damage from marine incidents. Loss of life/increased injury associated with marine incidents.

Opportunities
▪ Opportunity to work with Environment Canada to improve predictability in climate/weather/marine forecasts.

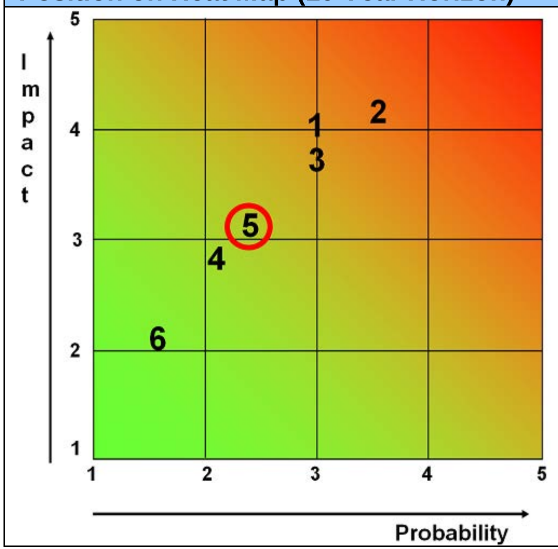
Gaps
▪ Unknown if changes in skill of marine forecasting especially for extreme events may cause increased Search and Rescue and Emergency Response activities. ▪ We don't understand how storminess (includes wave height) will change in the future. ▪ We don't understand how climate change is going to change the distribution of fish populations which affects the ability of CCG to plan for possible future Search and Rescue and Emergency Response events.

Appendix 6

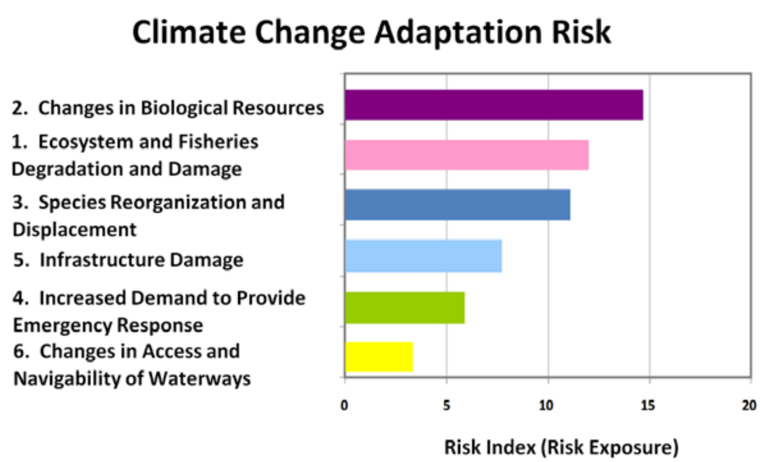
Risk summary sheet for the Infrastructure Damage (Risk 5) for the Pacific LAB. Each grouping of main risk drivers (left column) align with the grouping of potential opportunities- consequences (right column).

Pacific 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 (built infrastructure include: harbours, wharves, bases, stations, buoys, slipways, buildings, labs, lighthouses, navigation aids, hatcheries and DFO aquaculture activities).

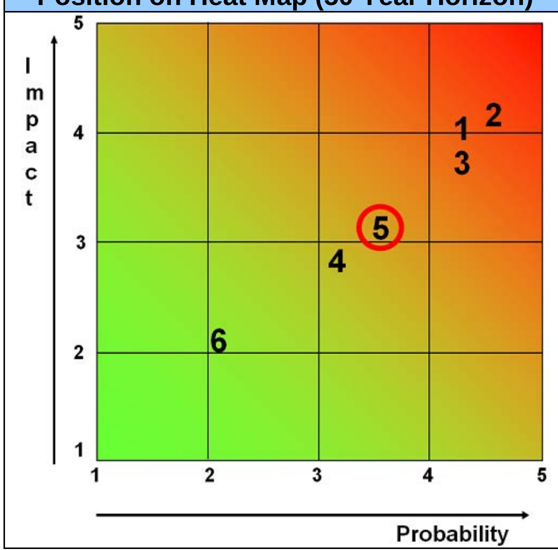
Position on Heat Map (10 Year Horizon)



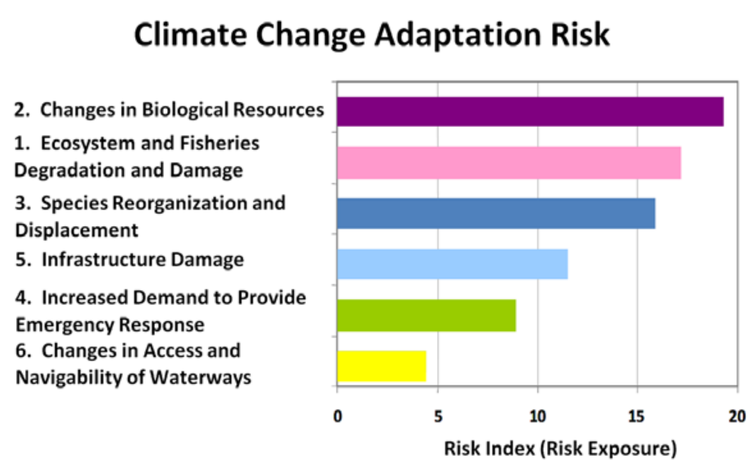
Risk Index (Probability x Impact) (10 Year Horizon)



Position on Heat Map (50 Year Horizon)



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



Main Risk Drivers	Potential Consequences: Threats
Changes in mean **sea level** may impact storm surge and freshet floods. **Stronger winds** and **changes in sea state** may **r**educe infrastructure integrity and effectiveness and may result in changes to shoreline configurations. Increased **water temperature** that increases biofouling may cause damage to DFO infrastructure. Climate change is expected to impact salmon enhancement facilities located in watersheds or areas that are currently very vulnerable to changes in **freshwater discharge.** Changes in **freshwater discharge** may impact navigational aids and waterway training infrastructure. Increased water temperature at salmon enhancement facilities located in watersheds or areas that are already vulnerable to high **freshwater temperature**, will lead to a greater need for colder groundwater resources or colder water drawn from deep lakes. **Changes to water dynamics (wind, precipitation, sea-level rise, temperature, salinity**) may impact small craft harbour infrastructure.	Light stations and coastal structures in general might be at risk due to storm surges. Various features of infrastructure may become inadequate (e.g. small craft harbours, vessels, breakwaters, wharfs, docks, fenders, ramps). Fishways at salmon enhancement facilities that have fish movement restricting counting devices may become less effective. Salmon enhancement facilities may need to be relocated or redesigned. Use of water resources by salmon enhancement facilities will be subject to competing uses and users. Damage to small craft harbours and increased higher costs of operation and/or relocation. Siltation, erosion, flooding and damage (caused by large logs and debris) of small craft harbours during extreme freshwater discharge events.

Opportunities
▪ None identified.

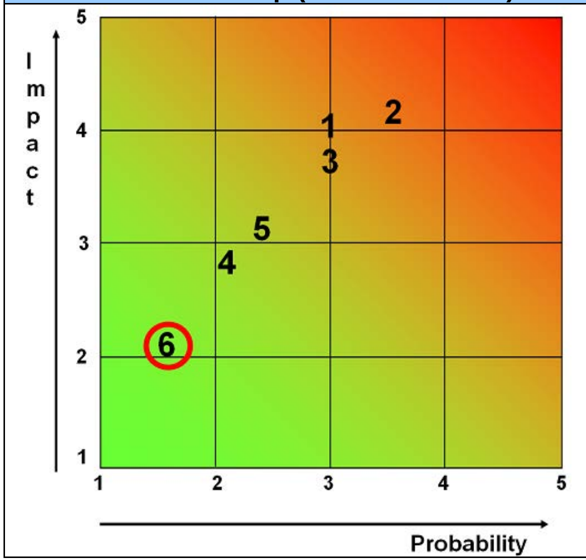
Gaps
▪ Extreme events in freshwater systems (droughts and floods) may be influential but need to be investigated further. ▪ Silt load associated with changes in streamflow require further investigation.

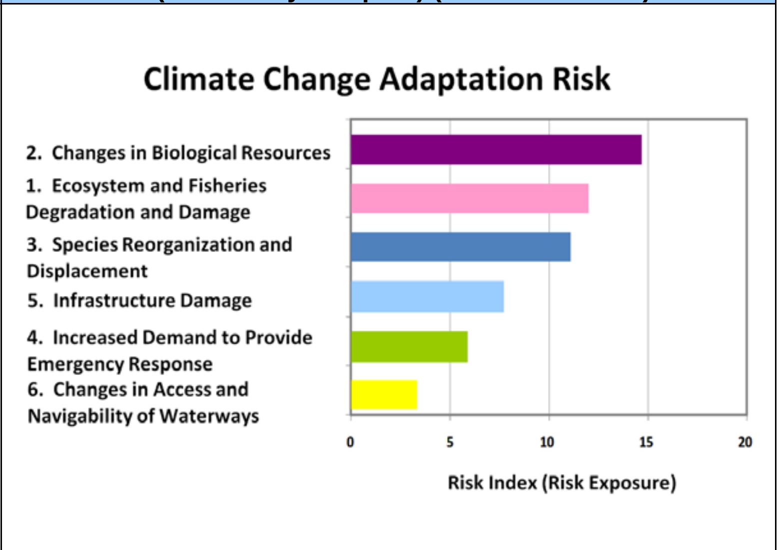
Appendix 7

Risk summary sheet for the Changes in Access and Navigability of Waterways (Risk 6) for the Pacific LAB. Each grouping of main risk drivers (left column) align with the grouping of potential opportunities- consequences (right column).

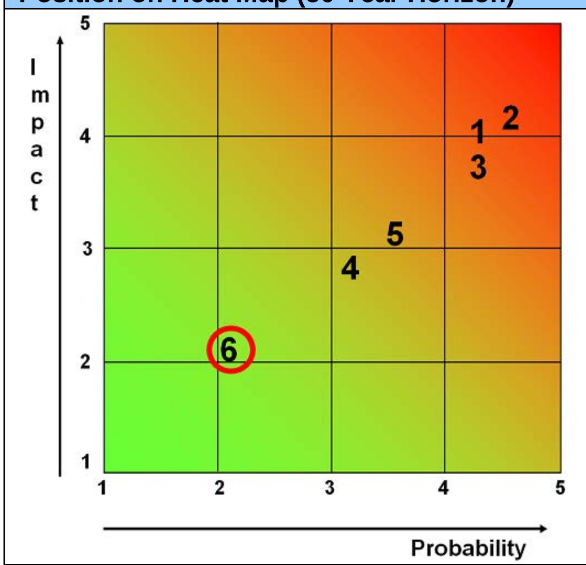
Pacific Large Aquatic Basin
Risk 6: Changes in Access and Navigability of Waterways
Risk Statement: There is a risk that climate change will affect DFO's ability to provide safe access to waterways.
Context: This risk deals with impeded access due to changes in factors such as sedimentation, water levels,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

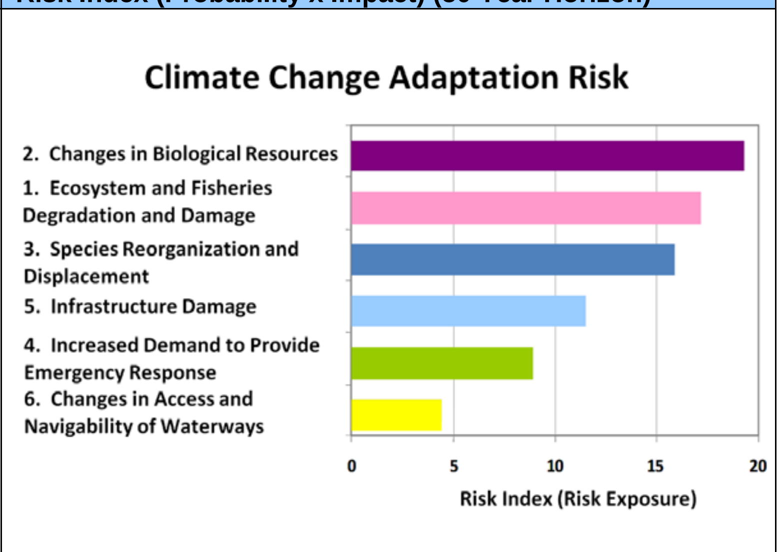
Position on Heat Map (10 Year Horizon)	Risk Index (Probability x Impact) (10 Year Horizon)





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





Main Risk Drivers	Potential Consequences: Threats
Increasing sea level and freshwater discharge may change effectiveness of waterway control structures (applies to Fraser River). Projected changes and associated **freshwater discharge and stratification** may result in greater need for dredging caused by increased sedimentation. Projected changes in mean **sea level, freshwater discharge and wind** will cause an increased need to update marine navigation charts and fixed aids to navigation.	Disruption of marine navigation. Increased debris during freshets and storm surges (pulling logs off beaches). Potential increase of maritime incidents including environmental and vessel collisions. Need to update tide tables and models.

Opportunities
▪ Potential to improve access or navigability in some areas.

Gaps
▪ Effects of coastal erosion not well understood. ▪ Currently there is low to no predictability of fog conditions. ▪ Better projections of sea level rise on a sub-basin scale are needed.

Appendix 8
Impact and probability ranking criteria used to assess DF'sO Departmental climate change risk.

Impact ranking (DFO Integrated Risk Management)

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

Probability ranking

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

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National Capital Region
Fisheries and Oceans Canada
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