DFO CLIMATE VARIABILITY AND CHANGE IMPACTS AND ADAPTATIONS RESEARCH FOR CANADA'S MARINE AND FRESHWATER FISHERIES: PROCEEDINGS OF A WORKSHOP HELD IN HALIFAX, APRIL 30-MAY 2, 2000, AND THE RESULTS OF A BACKGROUND REVIEW OF ACTIVITIES AND NEEDS

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OF FISHERIES AND AQUATIC SCIENCES 2575

DFO CLIMATE VARIABILITY AND CHANGE IMPACTS AND ADAPTATIONS RESEARCH FOR CANADA'S MARINE AND FRESHWATER FISHERIES: PROCEEDINGS OF A WORKSHOP HELD IN HALIFAX, APRIL 30-MAY 2, 2000, AND THE RESULTS OF A BACKGROUND REVIEW OF ACTIVITIES AND NEEDS

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EXECUTIVE OVERVIEW

This report contains a summary and the detailed record of the consultation process, and the conclusions and recommendations for developing a Department of Fisheries and Oceans' (DFO) climate impacts and adaptations research program. A program framework and some possible approaches are outlined.

The consultation process was facilitated with funding provided by the Government of Canada Climate Change Action Fund (CCAF) and had two components. The first component involved a review of DFO's current activities and needs for climate impacts and adaptations research. This review was conducted on contract by one-to-one interviews with a wide range of individuals across Canada, both within DFO and beyond. The report was completed in February 2000.

The second component involved a national workshop held in Halifax, April 30 to May 2, 2000. Participants in the workshop focussed on developing a framework for DFO's climate impacts and adaptations research on marine and freshwater fisheries. A number of key conclusions and recommendations arose from this process:

Conclusions

- Assessment of impacts and understanding of our capacity to adapt, as envisaged by the Intergovernmental Panel for Climate Change (IPCC) and the provisions of the Kyoto accord, for the Canadian fisheries sector is lagging far behind other sectors, such as agriculture, forestry, and energy.
- Incorporation of climate factors into our understanding and management of fisheries resources requires consideration of both variability and change in atmospheric and aquatic climates.
- Climate variability and change (CVC) are already impacting and will increasingly impact Canadian fish and fisheries.
- Appreciation of the CVC issue among DFO's scientists is high, but few departmental programs are specifically oriented to CVC impacts or adaptations.
- Awareness of the potential impacts of CVC is low among fishery resource users and little is known of the adaptive capacity of those users. Decisions being made now, without awareness of climate change impacts, could increase vulnerability in the longer term.
- DFO is unable, within existing research resources, to implement an I&A research program that is sufficient to meet the needs of the fishery sector. Sufficient resources are also needed within the department in order to lever funds from other programs such as the CCAF.
- Resource efficiencies can be realised by recognising overlaps between some areas of CVC research needs and the information needs for ecosystem management of fisheries resources.

- DFO clearly has the leadership role and responsibility for impacts and adaptations research in the fisheries sector, although collaboration with federal and provincial agencies, industry, universities, and other user groups will be essential.

Recommendations

- That DFO develop a national program to address CVC impacts and adaptation for Canada's marine and freshwater fisheries with four goals:
  - ◊ To identify regional, ecosystem, and fishery sensitivities and vulnerabilities induced by CVC.
  - ◊ To develop "plausible futures" for Canada's aquatic resources by region, ecosystem, and fishery.
  - ◊ To reinforce movement towards ecosystem management by incorporating incremental improvements in the understanding of climate variability and change effects into day-to-day management advice.
  - ◊ To help and enable the industry to adapt successfully to climate change by reducing negative impacts and taking advantage of new opportunities.
- That DFO implement and lead such a program by:
  - ◊ Summarising what DFO can say today about the impacts of CVC on fisheries and aquaculture resources, and ensuring that this information is distributed to clients,
  - ◊ Producing plausible regional and national impacts futures for all fishery resources,
  - ◊ Assessing the adaptive capacity and options of fishery users,
  - ◊ Increasing understanding of the spatial distribution of fish resources and changes in distribution (first priority), species productivity and composition, and genetic diversity,
  - ◊ Employing an integrated mixture of retrospective data-mining, simulation modelling, field and laboratory studies, and ecosystem monitoring, and
  - ◊ Collaborating regionally and nationally with clients, other agencies, user groups, and universities.
- That DFO implement the impact and adaptation research program as an integrated mission-oriented, non-competitive task, driven by an evolving framework of directed resource-management questions, and ensuring that all components are adequately addressed.
- That DFO appoint a full-time national coordinator in Ottawa, to
  - ◊ knowledgeably cover ocean climate and fisheries impacts and adaptations research relative to all aspects of the climate change issue, and
  - ◊ provide the linkage and coordination among regional activities and a liaison with other agencies involved in this program, especially with the DOE-NRCAN lead via the CCAF.
- That DFO establish an Ocean Climate and Fisheries Impacts and Adaptations Science Committee (with the national coordinator as secretariat),

◊ as an inter-regional research committee coordinating all aspects of the climate change research program for marine and freshwater resources, covering aquatic climate, fisheries impacts, and adaptation, and
◊ reporting directly to the National Science Directors Committee.

- That DFO seek incremental resources of approximately $8M per year for a period of 5 to 10 years, including provision for an infusion of new scientists necessary to implement this impacts and adaptations research program.

These recommendations will take time to implement and will need to be phased. The necessary resources will not likely be immediately available. How should DFO proceed until additional resources can be found? Several steps could be taken immediately.

- DFO should establish an Ocean Climate Science and Fisheries Impacts and Adaptations Committee, reporting to the National Science Directors Committee, to:

◊ Summarise what DFO-Science can say now about the impacts of CVC on fisheries and aquaculture.
◊ Assess what additional knowledge is needed to fulfill DFO's mandate, beginning with the information in this workshop report.
◊ Identify a few specific priorities, national or regional, for CVC research in DFO, building on this workshop report, the synthesis recommended above, and the work presently underway in Canada and internationally.
◊ Establish how current resources and programs can be used to meet those research priorities.
◊ Determine how the new resources allocated to DFO for the "Ecosystem" and "Precautionary" approaches can assist, complement, or support DFO's CVC research on these priorities.
◊ Identify which priorities could be considered for funding under the current High Priority Fund or others such as the Climate Fund, and under what guiding principles.
◊ Establish a national strategy to obtain funding from non-DFO sources such as the CCAF and CMOS.
◊ Ensure adequate linkages with national and international initiatives.
◊ Ensure adequate linkages with DFO's ocean modelling program.

RESUMÉ

Le présent rapport contient un résumé et le dossier détaillé du processus de consultation ainsi que les conclusions et recommandations relatives à l'élaboration d'un programme de recherche sur les impacts climatiques et les adaptations du ministère des Pêches et des Océans (MPO). Un cadre de programme et quelques approches possibles sont décrits.

Le processus de consultation a notamment été financé par le Fonds d'action pour le changement climatique (FACC) du gouvernement du Canada. Il était composé de deux volets. Le premier volet consistait en un examen des activités et des besoins actuels du MPO en ce qui concerne la recherche sur les impacts climatiques et les adaptations. Cet

examen a été mené dans le cadre d'un contrat sous forme d'entrevues face à face avec un vaste éventail d'individus dans tout le Canada, tant au sein du MPO qu'à l'externe. Le rapport a été terminé en février 2000.

Le deuxième volet consistait en un atelier national organisé à Halifax du 30 avril au 2 mai 2000. Les participants à l'atelier ont mis l'accent sur l'élaboration d'un cadre de recherche sur les impacts climatiques et les adaptations qui concerne les pêches en mer et en eau douce. Plusieurs conclusions et recommandations clés sont ressorties de ce processus :

Conclusions

- Le secteur canadien des pêches accuse un grand retard par rapport aux secteurs de l'agriculture, de la foresterie et de l'énergie pour ce qui est de l'évaluation des impacts et de la compréhension de la capacité de s'adapter, telles qu'elles sont envisagées par le Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) et les dispositions du Protocole de Kyoto.
- L'intégration des facteurs climatiques dans nos connaissances et mesures de gestion des ressources halieutiques doit tenir compte à la fois de la variabilité et du changement du climat de l'atmosphère et du milieu aquatique.
- La variabilité et le changement climatiques affectent déjà les poissons et les pêches au Canada, et leurs répercussions seront de plus en plus marquées.
- L'appréciation de la question de la variabilité et du changement climatiques chez les chercheurs du MPO est élevée. Pourtant, peu de programmes ministériels sont précisément orientés vers les impacts de la variabilité et du changement climatiques ou les adaptations.
- La sensibilisation aux impacts potentiels de la variabilité et du changement climatiques est faible parmi les utilisateurs des ressources halieutiques, et on en sait peu sur la capacité adaptative de ces utilisateurs. Des décisions prises maintenant, sans égard aux impacts du changement climatique, peuvent augmenter la vulnérabilité à long terme.
- Le MPO est incapable, avec les ressources existantes en recherche, de mettre en œuvre un programme de recherche sur les impacts et les adaptations permettant de répondre aux besoins du secteur des pêches. Des ressources suffisantes sont également requises au sein du Ministère afin de recueillir des fonds à partir d'autres programmes, dont le FACC.
- Le Ministère pourrait gérer efficacement ses ressources s'il reconnaissait les chevauchements entre certains aspects des besoins en recherche sur la variabilité et le changement climatiques et des besoins d'information pour la gestion écosystémique des ressources halieutiques.
- De toute évidence, le MPO est le chef de file et le responsable de la recherche sur les impacts et les adaptations dans le secteur des pêches, mais il est impératif qu'il collabore avec les organismes fédéraux et provinciaux, les industries, les universités et d'autres groupes d'utilisateurs.

Recommandations

- Le MPO doit mettre sur pied un programme national qui traite des impacts de la variabilité et du changement climatiques ainsi que des adaptations dans le secteur des pêches en mer et en eau douce au Canada. Le programme a quatre objectifs :
  - ◊ Identifier la sensibilité et la vulnérabilité des régions, des écosystèmes et des zones de pêche dues à la variabilité et au changement climatiques.
  - ◊ Élaborer des scénarios plausibles concernant les ressources aquatiques canadiennes selon les régions, les écosystèmes et les zones de pêche.
  - ◊ Favoriser davantage une gestion écosystémique en intégrant aux conseils de gestion quotidienne les dernières découvertes dans le domaine des effets de la variabilité et du changement climatiques.
  - ◊ Aider l'industrie et lui permettre de s'adapter au changement climatique en réduisant les impacts négatifs et en exploitant les nouvelles possibilités.
- Le MPO doit mettre en œuvre et diriger un tel programme :
  - ◊ en résumant tout ce qu'il peut affirmer aujourd'hui à propos des impacts de la variabilité et du changement climatiques sur les ressources halieutiques et aquacoles, et en s'assurant que l'information est transmise aux clients;
  - ◊ en prévoyant les impacts potentiels régionaux et nationaux sur toutes les ressources halieutiques;
  - ◊ en évaluant la capacité et les options d'adaptation des utilisateurs des ressources halieutiques;
  - ◊ en comprenant mieux la distribution spatiale des ressources halieutiques et les changements qu'elle subit (priorité), la productivité et la composition des espèces et la diversité génétique;
  - ◊ en recourant à un ensemble intégré de moyens, dont l'exploration de données rétrospectives, la modélisation de simulation, des études de terrain et de laboratoire, et la surveillance des écosystèmes;
  - ◊ en collaborant aux niveaux régional et national avec les clients, les autres organismes, les groupes d'utilisateurs et les universités.
- Le MPO doit mettre en œuvre le programme de recherche sur les impacts et les adaptations de manière intégrée, non compétitive et orientée vers la mission. Le programme doit être guidé par un cadre évolutif de questions axées sur la gestion des ressources. Tous les volets doivent être abordés adéquatement.
- Le MPO doit désigner un coordonnateur à plein temps à Ottawa :
  - ◊ qui abordera de manière compétente la recherche touchant le climat océanique, les impacts sur les pêches et les adaptations en ce qui concerne tous les aspects du changement climatique;
  - ◊ qui coordonnera et fera le lien entre les activités régionales en plus d'assurer la liaison avec les autres organismes concernés par ce programme, en particulier le département de l'Énergie des États-Unis et RNCan par l'entremise du FACC.
- Le MPO doit mettre sur pied un comité scientifique sur le climat océanique, les impacts sur les pêches et les adaptations (avec le coordonnateur national comme secrétaire) :

- ◊ qui, à titre de comité de recherche interrégional, coordonnera tous les aspects du programme de recherche sur le changement climatique en ce qui concerne les ressources marines et dulcicoles, lequel couvre le climat du milieu aquatique, les impacts sur les pêches et les adaptations;
  - ◊ qui se rapporte directement au Comité national des directeurs des Sciences.
- Le MPO doit solliciter des ressources supplémentaires (environ 8 M$ par année sur une période de 5 à 10 ans) et prévoir l'embauche de scientifiques en vue de mettre en œuvre le programme de recherche.

La mise en œuvre de ces recommandations, qui devra être progressive, prendra du temps. Les ressources nécessaires ne seront probablement pas disponibles immédiatement. De quelle manière le MPO devra- t-il procéder en attendant les ressources additionnelles? Plusieurs étapes peuvent être suivies immédiatement.

- Le MPO doit mettre sur pied un comité scientifique sur le climat océanique, les impacts sur les pêches et les adaptations (relevant du Comité national des directeurs des Sciences) qui devra :
  - ◊ résumer tout ce que peut maintenant affirmer le MPO-Sciences à propos des impacts de la variabilité et du changement climatiques sur les pêches et l'aquaculture;
  - ◊ évaluer quelles autres connaissances sont nécessaires pour permettre au MPO d'accomplir son mandat, en commençant par l'information incluse dans le rapport de l'atelier;
  - ◊ identifier certaines priorités nationales ou régionales de la recherche sur la variabilité et le changement climatiques au sein du MPO en se basant sur les composantes du rapport de l'atelier, le résumé recommandé ci-dessus et les travaux en cours au Canada et sur la scène internationale;
  - ◊ établir de quelle manière les ressources et les programmes actuels peuvent être utilisés pour respecter ces priorités de recherche;
  - ◊ déterminer comment les nouvelles ressources allouées au MPO pour l'approche écosystémique et l'approche préventive peuvent favoriser, compléter ou appuyer les recherches du MPO sur la variabilité et le changement climatiques relativement à ces priorités;
  - ◊ identifier quelles priorités pourraient être considérées à des fins de financement par l'actuel fonds d'action prioritaire ou d'autres fonds, dont le FACC, et déterminer selon quels principes directeurs il faut considérer ces priorités;
  - ◊ mettre sur pied une stratégie nationale pour obtenir des fonds de sources externes telles que le FACC et la Société canadienne de météorologie et d'océanographie (SCMO);
  - ◊ assurer des liens efficaces entre les initiatives nationales et les initiatives internationales;
  - ◊ assurer des liens efficaces avec le programme de modélisation océanique du MPO.

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INTRODUCTION

The Canadian Climate Action Fund (CCAF) was established by government to accelerate the development of science-based policies on climate change, and to inform Canadians about the underlying research and the implications of climate change to the economy, the environment, and society. Timely and accurate scientific information about the present and potential effects of global warming on resource sectors of the economy will help government in several ways, including:

- Participation in international discussions and negotiations;
- The development of long-range plans for the management of resource sectors;
- Provision of advice to the private sector to help them adapt to the effects of climate change.

In 1999, the CCAF Impacts and Adaptations program provided financial assistance for DFO to assess the current state of climate change research in Canada and to make recommendations for a comprehensive research program. Within DFO, a climate change research program should:

- improve understanding of the effects of climate variability and change on fisheries and aquatic ecosystems,
- deliver current understanding of these effects to internal and external clients, so enhancing their ability to plan for, manage, and adapt to the effects of climate change, and,
- allow DFO to meet its international responsibilities.

On April 30 to May 2, 2000, the DFO workshop on Climate Change Impact and Adaptations Science was held in Halifax, Nova Scotia, at the request of the National Science Directors Committee, DFO. This CCAF-supported workshop was a companion to one held earlier on ocean climate science. The Halifax workshop focussed on fisheries impacts and adaptation in marine and freshwater ecosystems. Approximately 40 people attended, representing the expertise of DFO (the majority), DOE, NRCAN, some provincial agencies, private sector interests, and universities.

Most of the workshop time was allocated to focussed discussion of program goals, issues, and potential directions. The proceedings are attached as Appendix 2, including:

- a summary, with recommendations,
- speaker abstracts,
- a section on goals and issues,
- the conclusions and recommendations from a discussion of three fundamental issues (basic science needs, the sensitivity and vulnerability of fish and aquatic ecosystems, and working with the industry), and
- a discussion of future directions for a program that would address specific regional climate science needs.

BACKGROUND

The purposes for the workshop and associated preparatory activities were detailed in a letter of agreement with the CCAF:

- To assess existing and needed climate impacts and adaptations research efforts and capacities in Canada, with options for further research, capacity building, networking, partnerships, etc., relative to fish and fisheries.
- To recommend steps for establishing the expertise and research directions on impact assessments, and for devising adaptation strategies, in partnership with other departments, provinces, universities, and the private sector, as appropriate.

After preliminary discussion with a representative advisory group, it was agreed that the workshop goal should be:

> **A national forum to develop a framework, strategy, and priorities for a DFO climate impacts and adaptations research program for Canada's marine and freshwater fisheries.**

It was also recognized that products developed should:

- take into account work underway and proposed in the 5NR departments,
- include a framework for allocating impacts and adaptations research resources internally,
- be consistent with the overall goals and objectives of the impacts and adaptation elements in the national implementation strategy on climate change, and
- be consistent with DFO Science roles and responsibilities and with the core business plan.

As background for the workshop, a review of DFO's activities and needs for climate impacts and adaptations research was completed in February 2000 (see Appendix 3: Climate change impacts and adaptations science: Activities and needs in DFO, prepared by R.C.H. Wilson of 2WE Associates Consulting Ltd.). The major finding of this study were:

1. In every region of the country, some activity is underway to evaluate the sensitivity or vulnerability of coastal and marine ecosystems to changes in one or more climate variables. Although a significant part of this work is taking place around the fringes of stock assessment and other issues, some projects have been planned specifically to meet impacts research objectives. These impacts research projects are, however, concentrated in three regions of the country: Pacific, Laurentian, and Maritimes.

2. DFO is, however, still on the ground floor in building an adaptations research program. Very little work is being done with communities, business, or other sectors to help them characterise the implications of the range of environmental conditions foreseen by climate models, and to adapt their operations accordingly.

3. Given all of the needs identified, DFO has already spread itself too thinly trying to tackle too many problems at the same time. A focussed approach with new resources is needed, for which a first step might be to cluster the requirements by region and by scope. A set of needs,

linked by scope and linked nationally and internationally, would provide DFO with a framework for an impacts and adaptations research program.

The National Science Directors Committee directed that the workshop be held as soon as possible and appointed a steering committee and chair to lead the activity. The services of R.C.H. Wilson of 2WE Associates Consulting Ltd. were retained to provide overall continuity and to plan, facilitate, and document the workshop. The chair, Dr. Ken Minns, was responsible for preparing the workshop summary and executive overview for this final report.

The workshop was organized around a series of context-setting presentations from a wide range of perspectives. For each day, the presentations were selected to complement the theme of focussed discussions. The abstracts of those presentations are provided in Appendix 2. On Day 1, participants were asked to express their suggestions and expectations for the development of a program to address fisheries impacts and adaptation. In small groups they were asked to develop draft national goals for the program. The day's objective was to develop a consensus view of the overall purpose of the program and to give guidance to successively more detailed discussions. On Day 2, participants were divided among three topic areas — basic science, impact assessment, and adaptation — and were asked to identify priorities for those areas. Again an objective was to secure a consensus on the kinds of activities needed regardless of geography, as a backdrop for the last day's discussions. On Day 3, participants were regrouped regionally into four areas — Pacific, Arctic, Inland Freshwaters, and Atlantic — and again asked to identify priorities and outline programs for those areas. Detailed notes on the workshop are provided in Appendix 2; a summary is provided below.

PROGRAM GOALS

Group discussions on the first day provided three complementary goals for the program:

1. **To identify regional, ecosystem, and fishery sensitivities and vulnerabilities induced by climate variability and change (CVC).**
   This requires that regional ecosystem scenarios for potential climate variability and change be used as a context for gauging the relative sensitivities and vulnerabilities of fisheries resources and their habitats.

2. **To develop "plausible futures" for Canada's aquatic resources by region, ecosystem, and fishery.**
   This requires active programs of modelling and monitoring: modelling to capture our understanding of ecosystems, taking into account forcing events and key processes, and to enable us to look at sensitivities to climate parameters and processes, and monitoring to provide early warning and continuing testing and validation of the models.

3. **To reinforce movement towards ecosystem management by incorporating incremental improvements in the understanding of climate variability and change impacts into day-to-day management advice.**

PROGRAM FRAMEWORK

On the second day, topic groups agreed on a series of priorities that could serve as a guide to scientists and managers.

1. Basic Science Program Priorities

The knowledge of many species and ecosystems is inadequate to develop and test impacts hypotheses. For these situations, workshop participants developed a consensus view of the necessary elements for a basic science program to fill in the gaps, and so enable work on the management and adaptation issues arising from CVC impacts on fisheries:

- *Identify key species* — regionally, in freshwater and marine ecosystems — that have an important ecosystem role and/or sustain important fisheries. The identification of critical knowledge gaps for potentially sensitive and resilient species and systems can lead to prioritisation of future activities.

- *Review and synthesise exiting knowledge* for key species and ecosystems, emphasising characteristics sensitive to CVC (see Topic Session B, Appendix 2).

- *Undertake biological and habitat research* to lead towards understanding of the ways in which those species might be sensitive and vulnerable to CVC. Several DFO programs already exist that might help along these lines (e.g. stock assessment, Atlantic Zone Monitoring Program).

- *Monitor key ecosystem characteristics* in a broadly representative suite of marine and freshwater fisheries.

- *Disseminate monitoring and research data* to the public and to the scientific community.

2. Impacts Research Priorities

Assessment of the sensitivity and vulnerability of key species should be the core of the Department's climate research program. This should not, however, be seen as a call to incorporate all DFO's biological research as into a new envelope under the guise of understanding CVC impacts. The objectives of work identified as part of this priority should be passed through a filter that links the proposed outputs to the adaptation needs of the fisheries and aquaculture sectors. Impacts research should support adaptation needs.

Impact assessment might involve the synthesis of information about sensitivity and vulnerability with the scenario outputs from Global Climate Models (GCMs) or Regional Climate Models (RCMs).

- *Assess what can be said now* about the impacts of CVC on fisheries and aquaculture, and communicate the findings to clients. One approach would be to summarise existing knowledge on a regional and ecosystem basis into a relative rating scheme (low-medium-high) combining gaps, uncertainty, sensitivity, adaptive capacity, and likely impacts.

- *Undertake regional retrospective studies,* both historical and paleological, that will provide insights into sensitivity and vulnerability.

- *Assess spatial changes in species, habitat, and ecosystem boundaries.* Two characteristics of distributional changes contribute to the importance of considering this feature first in any assessment.
  a) Distributions:
     - integrate many biological and physical processes that relate system responses to change,
     - are generally more "readily" observable, and
     - are generally supported by good historical information, e.g., from surveys, fishing activities, and traditional ecological knowledge.

  b) Changes in distributions generate changes in important socioeconomic consequences, such as:
     - changes in commercial fishing patterns,
     - changes in recreational and subsistence fishing subject to mobility constraints in some areas such as the North or Arctic, and
     - changes in distributions of species may be used by industry to identify aquaculture species that might thrive under the changed conditions.

- *Iteratively develop single-species, multi-species, and ecosystem models linking environmental variables and biological responses,* to integrate available knowledge and data, to identify critical scientific gaps, and to facilitate assessment of aquatic resource "futures" with CVC "futures."

- *Supplement monitoring and comparative assessments with a focussed program of experimentation in the laboratory, in mesocosms, and in whole ecosystems.*

3. Adaptations Research Priorities

Priorities for the assessment of adaptation capacity and options indicate a need to increase DFO's involvement with and understanding of the many facets of the fishery users in Canada.

- *Increase the participation of stakeholders* in review and decision-making on projects directed to CVC-fisheries effects. Increased stakeholder participation in the review and decision-making for Science projects about CVC effects would encourage identification of impacts projects that support adaptation needs and would increase acceptance of results and priorities.

- *Assess the resilience and adaptive capacity of stakeholders, users, and industry sectors* to deal with existing climate variability and future climate change.

- *Iteratively develop and report longer-term forecasts* in relation to "plausible climate futures" for a wide range of fisheries resources across Canada.

- *Improve methods for assessing and managing CVC-linked risks in both short- and long-term fisheries management.* Some aspects of this work will benefit from the recent announcement of resources to conduct research and implement a precautionary approach in fisheries management.

- *Develop a shared sense of mission by expanding the involvement of scientists in communicating CVC-fisheries knowledge and uncertainties to internal and external clients.*

Workshop participants identified four desirable case studies:

a) Assessment of the impacts on aquaculture and the capability of the industry to adapt and expand.

b) Integrated, comparative analysis of trends in salmon stocks on the east, north, and west coasts.

c) Assessment of the impacts of climate change on lobster, crab, and shrimp management where substantial resources changes have been seen.

d) Assessment of Arctic fisheries management challenges in a changing climate / socioeconomic environment, given the limited ability to formulate hypotheses.

REGIONAL APPROACHES

On the final day of the workshop, regional groups suggested regional approaches to meeting program goals, consistent with the program framework discussed the day before. While the studies identified below reflect the priorities of workshop participants, a national call for project proposals would produce other useful ideas. Topics below are not listed in priority order.

Pacific Coast Priorities

Changes in marine conditions and salmon stocks have been linked to the Aleutian Low Pressure Index and the temperature of the ocean surface layer. More work is needed to elucidate the mechanisms and response patterns.

- Investigate the role of CVC in the collapse of salmon stocks on the central coast.

- Continue work to assess CVC impacts on Fraser River salmon.
- Continue observational research and retrospective analyses of marine linkages, and
- Enhance efforts to develop dynamic ecosystem models that incorporate biophysical links to major climate variables, analogous to the East Coast CDEENA program.

The combination of CVC effects and domestic licensing policies could have unintended consequences for the industry, as well as for Canada's position internationally

- Undertake research to develop a strategy for incorporating north-south shifts in species distributions into domestic licensing policies and international treaty considerations.

We note here that while the present report was in preparation, the Canadian Centre for Climate Studies (CICS) published the proceedings of their workshop on "Sustainable Seafood in a Changing Climate" (www.cics.uvic.ca/workshop). The CICS workshop focused on supporting the adaptations required in the BC fisheries and aquaculture sectors. The major points to emerge in the proceedings were:

- BC fisheries have already been affected by climate change, whereas the aquaculture sector has not been.
- Impacts research priorities identified included:
  - how marine life adapts to changes at various time scales,
  - non-salmonids,
  - growth and mortality factors,
  - causes and life cycle timing for the changes seen in salmon.
- Scientists must "develop a detailed understanding of the consequences of climate change to oceanic and freshwater ecosystems and to the individual species living within them".
- The fisheries and aquaculture industries need analyses of the repercussions of climate change scenarios at regional and local scales.
- The fishing industry is looking for leadership in developing adaptation strategies.

Arctic and Northern, including Hudson Bay Priorities

As well as noting that this area accounts for the largest portion of Canada's aquatic resources, participants listed three key issues for this region:

a) Biological processes in the North have important differences from those in southern Canada.
b) Climate change is predicted to be the greatest in northern latitudes, but CVC effects are only one of several sources of change facing people in the region.
c) The effects on biota will be mostly indirect, resulting from changes in habitat characteristics.

It is widely accepted that there are enormous gaps in knowledge and data for the North, that research is expensive, and that there are few scientists working in the area. Recommended activities include:

- Further desk analyses in which biological or fisheries data can be linked retrospectively to climate-driven parameters, drawing on systematic summaries of existing information.
- Progressive development of models, starting with word models and moving on to more quantitative models, as knowledge and data permit.

- Expanded new data collection activities for northern fisheries indicators: marine mammals, Arctic char, Arctic cod, capelin, sandlance, and benthos in all geographic regions of the north.

Inland Freshwater Priorities

The major priority should be to ensure that there is a significant freshwater component in DFO's climate impacts program. There are important differences between freshwater and marine environments when it comes to CVC impacts. The distributions and thermal preferences of many freshwater species are known, and a start has been made at determining species responses to climate change.

Coordination and networking will require a real effort because there are many stakeholders involved in freshwater fisheries (government agencies, NGOs, user groups, universities, etc.).

A nodal framework for assessing CVC impacts and adaptation in freshwater fisheries was proposed, with five study areas clustered around a national synthesis program (all six nodes would consist of regional networks to ensure complete coverage):

- Systematic examination and modelling of species distributions and their boundaries.
- Quantification and modelling of the physical and chemical processes responding to CVC in lakes and rivers.
- Quantification and modelling of biological and ecosystem productivity responding to CVC in lakes and rivers.
- Measurement of fishery capacity (subsistence, commercial, and recreational), the utilization of productivity potential, and the scope for adaptation within and among fisheries.
- Embedding of the first four components into regional landscape and societal contexts and determination of the influence those contexts exert.
- Integration of the first five components into national and regional impact and adaptation assessments in relation to CVC scenarios and adaptation strategies.

Atlantic Coast and Gulf of St. Lawrence Priorities

Workshop participants emphasised the usefulness of updating a regional report on climate change effects, prepared over a decade ago:

- Update the report by KT Frank, RI Perry, KF Drinkwater, and WH Lear, 1988, "Changes in the fisheries of Atlantic Canada associated with global increases in atmospheric carbon dioxide: A preliminary report" (Can. Tech. Rep. Fish. Aquat. Sci. 1652).
- Undertake retrospective analyses involving data mining, hindcasting workshops, and expansion of retrospective climate and hydrological time series for comparisons with historical fisheries and other ecosystem data.

Several other priorities were discussed, including:

- Develop biophysical models to help identify critical data gaps, fill in missing information, and develop plausible futures.

- Undertake studies of species distributions and ecosystem productivity, coupled with investigations of specific physiological, ecological, and ecosystem processes.

IMPLEMENTATION PRIORITIES

In each day's discussions, numerous references were made to organisational, resource, and other issues. These discussions have been summarised below.

Program Strategy

- **Establish a national program management structure.**
  One approach could be to set up a coordinated scientific task force or committee to coordinate DFO's implementation of a climate impacts and adaptation research program, and to integrate and plan work on CVC impacts. Such a committee could also set national priorities, recommend research fund allocations and, through comprehensive oversight of the research being conducted, ensure that critical aspects of understanding are not overlooked. This committee would report to NSDC.

- **Strengthen the headquarters coordination function.**
  Climate variability and change has become an important issue. Workshop participants felt that the headquarters resources available for coordination and liaison should be augmented.

- **Coordinate implementation with a fisheries node in the CCAF-supported Climate Change Impacts and Adaptation Research Network (CCIARN), in order to link regionally-based studies and to foster a comparative approach among regions.**
  Climate variability and change has become an important issue. The CCIARN is national in scope, involving a broad range of researchers and interests (e.g., universities, provinces, First Nations, industry or industry associations). A fisheries node in the CCIARN would bring in interests outside DFO's, would help improve coordination, facilitate exchange of information and help to identify future research priorities for fisheries for the overall I&A research program. DFO might host a fisheries node at the headquarters level to help bring the views and concerns of these other groups into its policy and priority frameworks.

Resource Issues

- **Provide a stable funding process internally.**
  DFO is legally responsible for managing fisheries resources, and has adopted a precautionary approach. For reasons outline above, these two facts mean that DFO cannot afford to ignore CVC impacts and adaptation issues. Research into CVC must be adequately and regularly funded over the long term, primarily through internal Departmental allocations, rather than through the present system of competitive internal and external funding. A strong core program would help DFO take advantage of leveraged funding opportunities such as the CCAF to supplement departmental funding, and to steer leveraged funding towards DFO research goals. The time scale for CVC effects and the size of the task ahead dictates a multi-year effort. A stable project framework and stable funding processes for a time horizon of 5+ years would facilitate achieving goals.

- **Provide immediate funding for studies of historical changes in distributions, and preliminary assessment of sensitivities and resilience to potential changes.**
  One example would be to use available data from surveys. These projects should include consideration of aquaculture as an adaptive component.

Organisational Approaches and Issues

- **Species management groups should incorporate someone whose only role is to speak for longer-term considerations.**
  Resource management can be viewed at two time scales, although both can be addressed by the same management group. The day-to-day management process is the most familiar, but decisions on a seasonal basis should not be made without appreciation of the longer term perspective for the stocks under management. There is an example in the management process for Pacific halibut, where the Pacific Halibut Commission has hired a scientist to look at the long-term outlook. The stock is currently being managed for predicted recruitment declines over the next 8 years. There may be a need to consider a two part fishery management structure, one short term and one long term, with both reporting on an on-going basis.

SUMMARY AND CONCLUSIONS

A national workshop and a background report have been used to develop the goals and framework for a program to address the effects of climate variability and change (CVC) in DFO. Regional approaches and implementation priorities have also been suggested. Once validated by DFO management, these elements could be used as guidance by scientists and managers to implement a climate impacts and adaptations research program The framework and approaches recommended rest on several observations:

- Assessment of impacts and understanding of our capacity to adapt, as envisaged by the Intergovernmental Panel for Climate Change (IPCC) and the provisions of the Kyoto accord, for the Canadian fisheries sector is lagging far behind other sectors, such as agriculture, forestry, and energy.
- Incorporation of climate factors into our understanding and management of fisheries resources requires consideration of both variability and change in atmospheric and aquatic climates.
- Climate variability and change (CVC) are already impacting and will increasingly impact Canadian fish and fisheries.
- Appreciation of the CVC issue among DFO's scientists is high, but few departmental programs are specifically oriented to CVC impacts or adaptation.
- Awareness of the potential impacts of CVC is low among fishery resource users and little is known of the adaptive capacity of those users. Decisions being made now, without awareness of climate change impacts, could increase vulnerability in the longer term.

- ➢ DFO is unable, within existing research resources, to implement an I&A research program that is sufficient to meet the needs of the fishery sector. Sufficient resources are also needed within the department in order to lever funds from other programs such as the CCAF.
- ➢ Resource efficiencies can be realised by recognising overlaps between some areas of CVC research needs and the information needs for ecosystem management of fisheries resources.
- ➢ DFO clearly has the leadership role and responsibility for impacts and adaptation research in the fisheries sector, although collaboration with federal and provincial agencies, industry, universities, and other user groups will be essential.

RECOMMENDATIONS

- That DFO develop a national program to address CVC impacts and adaptation for Canada's marine and freshwater fisheries with four goals:
  - ◊ To identify regional, ecosystem, and fishery sensitivities and vulnerabilities induced by CVC.
  - ◊ To develop "plausible futures" for Canada's aquatic resources by region, ecosystem, and fishery.
  - ◊ To reinforce movement towards ecosystem management by incorporating incremental improvements in the understanding of climate variability and change effects into day-to-day management advice.
  - ◊ To help and enable the industry to adapt successfully to climate change by reducing negative impacts and taking advantage of new opportunities.
- That DFO implement and lead such a program by:
  - ◊ Producing plausible regional and national impacts futures for all fishery resources,
  - ◊ Assessing the adaptive capacity and options of fishery users,
  - ◊ Increasing understanding of the spatial distribution of fish resources, the ecological processes, and system dynamics,
  - ◊ Employing an integrated mixture of retrospective data-mining, simulation modelling, field and laboratory studies, and ecosystem monitoring, and
  - ◊ Collaborating regionally and nationally with clients, other agencies, user groups, and universities.
- That DFO implement the impact and adaptations research program as an integrated mission-oriented task, driven by an evolving framework of directed resource-management questions, and ensuring that all components are adequately addressed.
- That DFO appoint a full-time national coordinator in Ottawa, to
  - ◊ knowledgeably cover ocean climate and fisheries impacts and adaptations research relative to all aspects of the climate change issue, and
  - ◊ provide the linkage and coordination among regional activities and a liaison with other agencies involved in this program, especially with the DOE-NRCAN lead via the CCAF.
- That DFO establish an Ocean Climate Science and Fisheries Impacts and Adaptations Committee (with the national coordinator as secretariat),

- ◊ as an inter-regional research committee coordinating all aspects of the climate change research program for marine and freshwater resources, covering aquatic climate, fisheries impacts, and adaptation, and
- ◊ reporting to the National Science Directors Committee

- That DFO seek incremental resources of approximately $8M per year for a period of 5 to 10 years, including provision for an infusion of new scientists necessary to implement this impacts and adaptations research program.

These recommendations will take time to implement and will need to be phased. The necessary resources will not likely be immediately available. How should DFO proceed until additional resources can be found? Several steps could be taken immediately.

- DFO should establish an Ocean Climate Science and Fisheries Impacts and Adaptations Committee, reporting to the National Science Directors Committee, to:

  - ◊ Summarise what DFO-Science can say now about the impacts of CVC on fisheries and aquaculture.
  - ◊ Assess what additional knowledge is needed to fulfill DFO's mandate, beginning with the information in this workshop report.
  - ◊ Identify a few specific priorities, national or regional, for CVC research in DFO, building on this workshop report, the synthesis recommended above, and the work presently underway in Canada and internationally.
  - ◊ Establish how current resources and programs can be used to meet those research priorities.
  - ◊ Determine how the new resources allocated to DFO for the "Ecosystem" and "Precautionary" approaches can assist, complement, or support DFO's CVC research on these priorities.
  - ◊ Identify which priorities could be considered for funding under the current High Priority Fund or others such as the Climate Fund, and under what guiding principles.
  - ◊ Establish a national strategy to obtain funding from non-DFO sources such as the CCAF and CMOS.
  - ◊ Ensure adequate linkages with national and international initiatives.
  - ◊ Ensure adequate linkages with DFO's ocean modelling program.

ACKNOWLEDGEMENTS

The support and encouragement of the Climate Change Action Fund provided the resources and impetus for this effort to development an overall research framework for addressing climate variability and change impacts and adaptation in the Canadian fisheries sector. The National Science Director's Committee nudged the process from plan into action. Thanks to the many individuals who were consulted in the preliminary assessment of current activities or who participated in the Halifax workshop and those who helped with the scoping and organization of the workshop. Thanks to the speakers and to the session chairs and rapporteurs who helped make the workshop a success. Thanks especially to Savi Narayanan in Ottawa for providing advice and encouragement throughout the process. Many thanks to Bob Wilson of 2WE Associates Consulting Ltd for his effective and efficient organization and reporting, and especially for his tireless efforts in assembling the workshop program and the participants in Halifax. The report was edited by Fran Aitkens, ELS.

APPENDIX 1. LIST OF WORKSHOP PARTICIPANTS AND THOSE WHO REVIEWED THE REPORT

List of workshop participants and those who reviewed the report. All participants received the draft report for review. Names marked with an asterisk did not attend the workshop but were sent the draft report for review.

Prefix	First Name	Last Name	Affiliation	Agency/ Company	City	Prov
Dr.	Dick	Beamish	Science	DFO	Nanaimo	BC
Mr.	Martin	Bergmann*	Oceans Program	DFO	Winnipeg	MB
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Dr.	Martin	Castonguay	Marine Fish, Mammals	DFO	Mont-Joli	QB
Mr.	Murray	Chatwin		Ocean Fisheries Ltd.	N. Vancouver	BC
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Dr.	Jeff	Curtis	Dept. of Earth & Environmental Sci.	Okanagan University College	Kelowna	BC
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Dr.	Brad	deYoung	Dept. of Physics & Physical Oceanogr.	Memorial University of Nfld.	St. John's	NF
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APPENDIX 2. PROCEEDINGS OF THE HALIFAX WORKSHOP ON CLIMATE IMPACTS AND ADAPTATIONS SCIENCE, APRIL 30 – MAY 2, 2000

Group Exercise to Develop GOALS and Outline ISSUES

As an introduction to later sessions of the workshop, participants were challenged to identify national and regional goals for Science Branch, and to discuss related issues. Several of the themes outlined below re-emerged later in the workshop.

The exercise was performed in five groups, each of six to eight people.

National Goals

The goals listed below were identified and endorsed by workshop participants.

- *Develop and test biological models.* Ecosystem models, whose sensitivity to climate variables can be tested, represent the ultimate product for DFO's climate change research program. Participants observed that these same models would help support an ecosystem approach to fisheries management. Although this is a national goal, it is understood that models will be developed at a sub-regional scale. They will require
    - the development of monitoring programs for key variables,
    - access to large data sets,
    - evaluation of existing ecosystem data, and
    - critical process studies

  GCMs do not all perform the same, and in general they simulate historical climate parameters with varying degrees of accuracy. There is no one best model. Realistic biological scenarios should be based on the range of changes predicted by several coupled ocean-atmosphere models.

- *Understand how aquatic ecosystems will respond*. Researchers and managers must recognise that ecosystems are unstable at decadal scales. Identifying changes means understanding the processes in ecosystems, and eventually linking ecosystem responses to GCM projections of future conditions. As a start, the qualitative nature and direction of biological responses to changes in the physical environment should be investigated for key commercial and non-commercial species. Investigations into non-commercial species will help separate the effects of fishing from those of climate change.

  Physical climate models suggest that climate variability, seasonal changes and events at the scale of weather are all important sources of change, but from an effects perspective climate variability seems more important today than climate change. An ability to distinguish variability from trends is important, as is the separation of natural from anthropogenic changes. Two scientific approaches are necessary:
    - single species, process-oriented studies;
    - a multi-species approach, based on ecosystem modelling

  Both top down (direct effects) and bottom-up (effects mediated through the food web) studies were recommended.

Participants would prefer to work in geographic areas where the signal-to-noise ratio is likely to be high. Examples suggested were:

- comparative studies in closed freshwater systems, to look at effects in the headwaters compared to effects downstream;
- studies in lakes, where warming will decrease the habitat of cold water species;
- studies of species at the geographic limits of their range;
- studies of anadromous species, with an extreme hypothesis being that some char and salmon might adapt to lakes and not go to sea anymore due to reductions in saltwater habitat;
- studies in the Arctic, where there will be high climatic and cultural impacts, and the magnitude of changes will be higher.

- *Develop the capacity for a strong research program.* Monitoring is but one of the pillars of understanding. Science-based projections of impacts should be developed within an appropriate time well before effects occur, in order to develop adaptation strategies for harvest management and external clients. After years of restraint, adequate resources must be provided if DFO is to meet the scientific responsibilities. Progress depends on three critical elements*:*
    - the supply of willing, capable scientists and support staff
    - adequate operational funding
    - a supportive infrastructure (e.g., information technology, vessels, field capability)

- *Integrate results nationally.* A strong national coordinator is required to integrate the results of regional programs, and to represent scientific progress interdepartmentally and to senior officials of the Department. Regional programs will focus on understanding the responses of different species groupings, but the three coasts may be more similar than meets the eye. Commonalities are likely to emerge.

    A comparative approach to the forecasts for different stocks will challenge inter-regional communications.

Regional Goals

Regional goals should promote achievement of the national goals. Workshop participants agreed that two types of study promise to do so.

- *Case studies.* Case studies involving process studies and biological models will provide a way to develop process insight, and will be useful for ecosystem management no matter what happens to climate. The species and systems selected for case studies should meet one or more criteria, including being:
    - sentinel or indicator species, including species at the top trophic level which will of necessity integrate other biological information;
    - species which cross boundaries. In doing so they are challenged by a range of environmental circumstances, promoting a high signal-to-noise ratio;
    - species that are socially and economically relevant, to promote buy-in;
    - species with wide distribution ranges, where the impacts of climate variability and change (CVC) will depend on what happens at the extremes.

Finally, the scope of studies should be tractable geographically and from a physical/ chemical perspective.

Process studies should build towards case studies by helping to couple physical and biological systems, and by identifying sensitivities. The degree to which physics can be linked with biological function and structure improves the accuracy of biological scenarios, particularly at the lower end of the food chain.

The design of case studies will require careful planning. The results should be discussed nationally, and used as windows of opportunity to understand commonalties.

- *Monitoring ecosystem characteristics.* Long-term and consistent time series data are vital to detecting change and should act as a sentinel for the types of changes to be faced. To be effective, CVC process studies and ecosystem models both require a strong base of species/system monitoring, e.g., to develop and verify models and hypotheses. The goals of monitoring need to be defined in terms of these requirements, to allow parameter selection and measurements to be connected with process studies. Once requirements are established, a hypothesis-based approach should be taken, consistent with building a relevant, long-term data base. However, monitoring requirements will change as we improve our understanding; a review mechanism must therefore be built in.

  Monitoring programs can use and build on fisheries surveys such as the Atlantic groundfish surveys, and can incorporate fisheries statistics. More long time series are needed, however, especially in the Arctic. It was pointed out that monitoring requires a sustained, long-term commitment, a constant or consistent methodology, and an integrated approach to logistics and data management.

Issues

Several factors should be considered in the development of national and regional projects.

- *Need for regional climate scenarios.* Resource biologists need continuing dialogue with the ocean modelling community about the outputs needed to support impacts and adaptations research. While GCMs suggest the direction of changes in temperature and precipitation over the land and oceans, the resolution available from the present generation of climate models does not support the development of accurate effects forecasting at an ecosystem scale. Coupled ocean-atmosphere models with resolution at a scale of less than half a degree are required to predict impacts. It is not clear whether improvements will come from the development of regional models, or through improvements in global models.

- *Capacity development.* Capacity development was identified as both a goal and an issue. There was general concern about both the amount of work that needs to be done and the expertise available. The constraint that producing annual stock assessments has on DFO's capability for doing other kinds of research must be recognised and addressed.

Given previous budget cuts and the other issues addressed by DFO Science, commitments of both money and people are needed. The supply of people must be appropriate, and the people will need ample time to work on the topic. DFO is very short of "numerically-oriented" biologists and biological modellers; these are required to interact more efficiently with the physical modellers and also to develop bio-physical models.

- *Retrospective analysis.* Several participants endorsed the value of using existing data to make inferences about species vulnerabilities. However, while retrospective studies are informative, and inexpensive compared to field investigations, it is generally inappropriate to use them to make projections for changes outside the historical range. This will be a problem.

- *Information transfer*. Human coastal communities will have to adapt, but the rate of change may present problems. Are there thresholds for adaptation in natural resources or in communities? The regulatory context in which fishing takes place (e.g., gear and geographic licensing constraints) complicates adaptation in the industry and reduces the flexibility for adaptation theoretically available.

  A successful adaptations program depends on extended discussions between scientists, fisheries managers, the industry(s), and other stakeholders. After impacts have been projected, consultations should take place between scientists, industry and management to address adaptation concerns. Partnerships are particularly important for new or expanded, long-term programs. Stakeholders should be brought into the process early and often to develop their understanding and support. Partnership development needs to be undertaken with a full range of stakeholders and evaluated to see that the mechanism is working properly. Concentricity of funding and goals are important, and specific questions of stakeholders, such as those raised by industry speakers, should be addressed.

  DFO must develop a series of national and regional messages that the Department wants stakeholders to hear. A three-step process should be undertaken without delay.

  1. A working group should be given the task of summarising what Science can say NOW about the impacts of CVC on fisheries and aquaculture.
  2. The working group should identify what else needs to be said to allow for the proper adaptation of impacted communities, especially those for which the adaptive capacity is small and the impacts are expected to be large.
  3. The working group should determine how to obtain the necessary knowledge and information.

Topic Session (A): ***BASIC SCIENCE NEEDS***

(Chair: Jim Reist; Reporter: Denis Gilbert)

Participants: Martin Castonguay, Brian Dempson, Ken Frank, Denis Gilbert, Glen Harrison, Yvan Lambert, Rob Macdonald, Savi Narayanan, Charles O'Reilly, Jim Reist, Yvan Simard, Michael Turner, Kevin Murphy, Brad deYoung, Brian Shuter.

The session discussed national goals, immediate actions for DFO at the national level, and an organisational approach to achieving the goals.

Goal

> *The most important national goal was felt to be the development of "plausible futures" for aquatic resources*

The phrase is equivalent to the development of "scenarios" for the physical climate of the future. Plausible futures would then place boundaries around expected climate change impacts on the resources from which reasonable adaptation strategies could be developed. These plausible futures would be derived from monitoring, retrospective analysis, and modelling changes in the distribution and productivity of important aquatic resources. Changes in the timing and composition of the spring algal bloom, for example, will likely be reflected in changes throughout the ecosystem.

Two types of products are needed to achieve the goal:

1) Models to understand the ecosystem that take into account forcing events and key processes, and to enable us to look at sensitivities to climate parameters and processes.
2) Monitoring to provide early warning and continuing validation of the models.

Immediate Actions

The development of plausible futures rests on making progress through a linked series of studies. Each step in the chain will contribute to a growing understanding of the response of fisheries resources to climate change.

1. *Identify key species.* Each region should identify key species for potential study, including species important in the structure and function of freshwater and marine ecosystems, as well as those species that sustain fisheries.
2. *Understand in what ways they are sensitive and vulnerable.* Once these key species have been identified, process studies should be undertaken to characterise their sensitivity and vulnerability to climate change. Process studies should include those directed towards predation and interaction of key species with exotics.
3. *Monitor key ecosystem characteristics.* Monitoring is a critical underpinning of an impact research program. Present monitoring programs should generally be continued, and enhancements should be directed towards collecting the time-series data needed for process understanding and ecosystem modelling. Monitoring should be directed towards: detecting change in distributions (e.g., range contraction of northern species; the

northward shift of warmer-water species); observing change in migratory patterns; and, detecting changes in growth, reproduction, and natural mortality.

4. *Make monitoring and research data available.* Monitoring data and as much research data as possible should be incorporated into publicly available databases, where they can be used by other scientists.
5. *Retrospective studies may provide insight into sensitivity and vulnerability.* Retrospective studies that link changes in distribution, behaviour and abundance to physical parameters should be undertaken to gain insight into the significance of the scenarios being developed by climate modellers. Climate variability impacts studies are relevant to impacts studies of climate change. Several regional case studies are needed to look at the implications of extreme historical events and climate variability on aquatic resources.
6. *Supplement with an experimental program.* Laboratory or mesocosm studies should be conducted to manipulate key physical, chemical, and biological parameters used in single-species or multi-species models.
7. *Develop models.* A whole suite of single-species and multi-species models are required, in which environmental variables (e.g., temperature, ice cover) can be manipulated to characterise the range of biological changes that may take place.

We are not as much in the dark as some people might think. As a starting point, existing knowledge could be summarised on a regional or ecosystem basis into sensitivity-adaptation tables, with cell entries low to high, e.g.:

	Sensitivity	Adaptive capacity	Likely Impacts
Species A	Medium	Low	Medium – high?
Species B	High	High	medium?
Species C	High	Small	Very high
Species D	Small	High	Very low
Species E	Small	Medium	Low
Species F	Medium	Small	High

Much of the environmental information collected during stock assessments is being used for work on Climate Variability and Change (CVC) impacts, but there may be a need to implement, enhance and reinforce this approach in certain cases, as well as for integrating stock-specific climate information and its significance across many individual stock assessments.

State-of-the-Oceans programs are very valuable in documenting physical changes to the ocean and freshwater environments. It was pointed out that these activities exist for the Pacific and Atlantic coasts, but not for the North, where monitoring data are scarce. The Arctic Science Planning Initiative (ASPI), if successful, will provide funding for increased work in the Arctic. Given the large climate change signal expected there, ASPI projects will likely contribute significantly to understanding the interaction between the arctic environment and the biota and thus enhance understanding of potential climate change impacts for this area.

A national impacts research program should be accompanied by continuous evaluation of changes in the social and economic structure of the fisheries. Adaptation studies have strong social and economic implications to the well being of coastal communities. Communication between fisheries managers and stakeholders in the fishery is regular, implying that scientific information should similarly be communicated to the managers on a regular basis.

Organizational Approach

Work across the Department and between DFO and other resource agencies should be co-ordinated nationally.

- *Establish a national program management structure.* One approach could be to set up a headquarters-chaired task force or committee to co-ordinate all aspects of the Impacts and Adaptations Climate Research Program, to integrate and plan work on CVC impacts. Such a committee could also set national priorities, recommend research fund allocations, and through comprehensive oversight of the research being conducted ensure critical aspects of understanding are not overlooked.
- *Provide a stable funding process.* Given the significance of climate change, its impacts and the needed adaptation strategies, research into CVC must be adequately and regularly funded over the long term, primarily through internal Departmental allocations rather than through the present system of competitive internal and external funding.

It is important to note that the results from the approach suggested above will not only enhance understanding of CVC impacts on aquatic ecosystems and biota, but will also increase our understanding of basic aquatic ecosystem structure, function and response to perturbations and change. From such understanding effective adaptation options can be developed for CVC impacts, and additionally, such research and monitoring has added value for assessing and accommodating impacts other than those associated with climate change.

Topic Session (B): ***FISH/ ECOSYSTEM SENSITIVITIES & VULNERABILITIES***

(Chair: Ian Perry, Reporter: Jacques Gagné)

Participants: Ian Perry, Jacques Gagné, Paul Keiser, Ken Mills, Jeff Curtis, Rob Stewart, Alida Bundy, Roger Street, Bob Rutherford, Ken Drinkwater

Participants proposed a national goal and a pathway towards it. The characteristics of biological systems were discussed, with distribution being identified as the most important for study. Three recommendations were made.

Goal

To identify ecosystem sensitivities and vulnerabilities induced by climate variability and change

This goal comprises at least two steps:

1) What are the scenarios (by Region) for potential climate changes?
2) What are the relative sensitivities and vulnerabilities to these potential changes?
   - Are some systems more sensitive, and others more resilient?

There was also recognition that

Impacts = probability + consequences

Approaches

Retrospective analyses and modelling are the two general approaches most likely to determine system sensitivities and vulnerabilities to climate changes:

- *Retrospective analyses.* Retrospective analyses include two classes of data with very different time scales:
    - Historical data
    - Paleo data

  Historical data include research vessel surveys, fishing information, etc., which provide time series views of changes over the past few to several decades. Paleo data sources provide information on changes over much longer time periods, but usually with lower species and spatial resolutions.

- *Modelling.* Modelling is a tool for data integration <u>and</u> scenario development. Models combine physical and biological data, identify critical “control” parameters which may be in need of improved data, and can be used to develop possible future scenarios. However, development of adequate models and improvements of physical – biological connections will take time, and development of socioeconomic components to these models will take considerably more time. The strong consensus among Working Group members was not to wait – to use models and information now available to integrate data and to develop future scenarios.

The group recognised the problems with extrapolating past conditions to possible future situations, when those future conditions may extend considerably beyond past situations. Extrapolating "outside the box". These circumstances may require fresh studies to contribute to the modelling exercise.

System "Characteristics"

System characteristics were identified which are likely to be sensitive to climate changes, and which are likely to be observable by monitoring programs. These features are:

- Distribution
- Growth / Condition
- Diversity – genetic (and species)
- System productivity
- Life-history bottlenecks
- Species composition (redundancy)
- Predator-prey interactions

System productivity combines changes (or not) of productivity, but also changes in species composition, for example where system productivity might remain constant yet how that productivity is apportioned among species is markedly different. Species composition also includes redundancy of species, for example the replacement of one species by an ecologically similar species, so that total system functioning does not change.

Genetic diversity is important, in particular for species at the extremes of their distributional ranges. It is likely that populations in these marginal environments may possess greater genetic diversity than populations in the middle of their range. The ability of a species to adapt to or evolve with environmental changes requires adequate genetic diversity and may thus be greater in marginal environments. The group also noted that commercially exploited populations may be fished to extinction before they have the time to adapt to a rapidly changing environment.

Of these system characteristics, there was a consensus that <u>distribution</u> ranked as the first feature that should be considered in any general study of species and ecosystem sensitivities to climate variation and change. This was for several reasons. Distribution:

- Integrates many biological and physical processes that relate system responses to change;
- Generally is "readily" observable;
- Generally has good historical information, e.g. from surveys, fishing activities, and traditional ecological knowledge.
- Changes in distribution generate important social consequences, such as
  - Changes in commercial fishing patterns
  - Changes in recreational / subsistence fishing (the working group noted the reduced mobility of arctic communities from their historical nature (?))
- Changes in distributions of species may be used by industry to identify aquaculture species that might thrive under the changed conditions.

The second choice for a system characteristic to monitor is growth and condition of fish. These are also generally readily observed, and can lead to changes in distribution. However, it was also noted that changes in growth and condition may have more interannual variability, and therefore can be more difficult to interpret without large ambiguities.

Recommendations

The working group made three recommendations:

1. *Each DFO region should develop regional scenarios for changes in physical conditions, and conduct analyses of sensitivity / vulnerability to determine critical species / habitats / ecosystems*, i.e., based on best available current knowledge, to identify potentially sensitive and resilient species and systems; to identify critical knowledge gaps; and then to prioritise the findings for further work. The example in hand is the Frank *et al*. 1988 report (Frank, K.T., R.I. Perry, K.F. Drinkwater, and W.H. Lear. 1988. Changes in the fisheries of Atlantic Canada associated with global increases in atmospheric carbon dioxide: a preliminary report. Can. Tech. Rep. Fish. Aquat. Sci. 1652.)

2. *Funding should be made available for studies of historical changes in distributions, and sensitivities / resilience to potential changes*, for example using available data from surveys. These projects should include consideration of aquaculture as an adaptive component.

3. *A Fisheries Node in the CCAF-supported climate-change impacts and adaptations network should be established*, in order to link these regionally-based studies and to foster a comparative approach among regions.

Topic Session (C): ***DEVELOPING FISHERIES FORECASTS AND WORKING WITH THE INDUSTRY***

(Chair: Dick Beamish, Reporter: Ken Minns)

Participants: Fred Page, Denis d'Amours, Pam Kertland, Dick Beamish, Ken Minns, Murray Chatwin, Tony Charles, Bob Wilson

The session developed a national goal and general activities that would help achieve it. Organisational issues were discussed and case studies were identified to meet national information gaps.

Goal

Science should reinforce the move towards ecosystem management by incorporating incremental improvements in the understanding of climate-related effects into day-to-day management advice

Fisheries managers and stakeholders need information about the effects of climate variability and change on an ongoing basis. While departmental managers now talk about ecosystem management, the practice today amounts to single species management that incorporates some consideration of CVC. Biological forecasts should be iteratively improved to reflect new outputs from physical and biological models, and the suite of species for which forecasts are available should be broadened.

Objectives

1. *Expand scientist involvement in communicating CVC-fisheries knowledge and uncertainties beyond DFO.* Scientists should devote more time to telling people outside the Department what they know and how certain they are (or are not) about specific outcomes.

2. *Increase stakeholder participation in the review and decision-making on projects directed to CVC-fisheries effects.* To promote industry and sector buy-in to long term forecasts, incorporation of increased, effective communication of data, knowledge, and uncertainties is needed among all parties. Increased stakeholder participation in the review and decision-making for Science projects about CVC effects would encourage identification of impacts projects that support adaptation needs and would increase acceptance of results and priorities.

3. *Assessment of the stakeholder/user/industry sectors' resilience and adaptive capacity.* Along with improvements in long term forecasts, the Department needs a better understanding of the user end of the system, focused on learning the stakeholder/user/industry sector's resilience and adaptive capacity. While this type of activity is not traditionally done by Science, it is an important information need for the Canadian Climate Program. CCAF submissions for working with the fisheries industry sector are perhaps the lowest of any resource sector.

4. *Iterative development and reporting of longer-term forecasts in relation to "plausible climate futures" for a wide range of fisheries resources across Canada.* This activity is already underway for a wide range of fisheries resources is already underway. On the West

coast, where the Pacific Fisheries Resource and Conservation Council (PFRCC) has identified salmon as the most important issue for CVC studies, the development of "plausible futures" is well underway. In the Maritimes, CVC information has been used to develop allocations and the management strategy for snow crab.

5. *Improved methods for assessing and managing CVC-linked risk in both short- and long-term fisheries management.* While improvements can be made in the way in which scientific uncertainty is reflected in management plans, better methods for are needed for risk assessment and risk management for both short-term and longer-term fisheries management. Long range forecasts have to recognise at least five types of uncertainty:
    - Randomness and unpredictability in the future state of the physical environment
    - The probability that species will respond to changes in the physical state in different ways
    - Incomplete descriptions of the present state of ecosystems
    - Uncertainties and approximations in model parameters and linkages
    - Responses in the fishing community to changes in management strategy based on their objectives and perceptions
    - The range of institutional responses and approaches towards management of species affected by CVC

    The many uncertainties involved fully justify taking a precautionary approach.

Longer-term forecasts for commercial species are a prerequisite to assessing the economic impact of climate change on Canadian fisheries. While a national economic assessment would fit into the CCPB's strategy, the shortage of impacts predictions makes it infeasible to consider doing one in the near-term.

Organisational Approaches/Issues

- *DFO should strengthen its headquarters coordination function.* Climate change has become an important issue. Workshop participants felt that the headquarters resources available for coordination and liaison should be reinforced. Any regional process or structure should be reflected in a parallel structure in headquarters.

- *A stable project framework and processes for a time horizon of 5+ years would facilitate achieving goals.* The time scale for CVC effects and the size of the task ahead dictates a multi-year effort. DFO should strive for continuity in the funding process

- *There may be a need to consider a two part fishery management structure, one short-term and one long-term with both reporting on an on-going basis.* According to John Caddy, there may be two time scales for resource management, although the same group may perform both functions. The day-to-day management process is the most familiar, but the day-to-day decisions should not be made without appreciation of the longer term perspective for stocks under management.

- *Species management groups should incorporate someone whose only role is to speak for longer-term considerations.* There is an example in the management process for Pacific halibut, where the Pacific Halibut Commission has hired a scientist to look at the long-term outlook. The stock is currently being managed for predicted recruitment declines over the next eight years.

Case Studies

Four desirable case studies were identified:

1. *Impacts on aquaculture and the capability of the industry to adapt and expand.* While the aquaculture industry is seen by some as an adaptation strategy for declines in Canada's fishing industry, there is almost no Canadian literature on the possible effects of climate change on aquaculture, and little published information world-wide.

2. *Analysis of trends in the East and West coast salmon stocks.* Such an analysis has to integrate changes in the freshwater and marine environments. In-river temperature rises and changes in coastal/ marine conditions and productivity could seriously limit future distribution. The study could also include salmonids in the Arctic (char stocks and the now-documented expansion of Pacific salmon into the western Arctic).

3. *Impact of climate change on lobster, crab, and shrimp management.* Substantial changes have been seen in these resources, and long-term assessments would better inform management decisions.

4. *Arctic fisheries management challenges* in a changing climate/ socioeconomic environment, given the limited ability to formulate hypotheses.

***Region Session (A):* PACIFIC COAST**

(Chair: Dick Beamish; Reporter: Bob Wilson)

Participants: Dick Beamish, Denis d'Amours, Murray Chatwin, Bob Wilson
(Incorporating subsequent comments from David Welch)

The workshop reached consensus on three essential elements for the Pacific program. An additional international research component was generally supported, but participants were unsure if an international element would be funded.

The session began with discussion about why DFO scientists had been so relatively unsuccessful at getting resources to explore climate change effects. Although it was pointed out in the plenary that fisheries issues took about 15% of the first cycle CCAF funding, about the right share, internal allocations for climate work have been low compared to the resources available for other areas of Science susceptible to Climate Variability and Change (CVC) effects (e.g., salmon stock assessment), and to related activities in the Pacific Region (e.g., salmon enhancement). While scientific presentations to date have succeeded in getting climate change issues related to salmon onto the agenda of management groups in the Region and nationally, one conclusion that can be drawn is that scientists involved in CVC investigations should spend more time communicating about the issues.

Freshwater Ecosystems

The importance of salmon to BC makes a freshwater element to the Region's CVC program essential. In addition, the Pacific Fisheries Resources Conservation Council (PFRCC has identified the future of salmon stocks as an important issue. The Canadian catch has been declining since about 1989, at a time when the all-nations catch in the Pacific is rising. Steelhead stocks are in very poor shape, but the reasons for their decline are not well understood.

Participants concluded that a project should be put forward to investigate the role of climate variability in the declining abundance of salmon (including steelhead) on the central coast. Two possibilities have been suggested.

1. *Investigate causes for the collapse of salmon stocks on the central coast.* Salmon stocks on the central are collapsing. The magnitude of the decline is both serious and difficult to understand, but it appears to be a function of more than fishing pressure. It will not be easy to understand this issue, and work on testable hypotheses is urgently needed. The scientific effort invested in central coast stocks has been low in the past. Much of the area is very sparsely inhabited, and habitat loss and degradation has been relatively low, although logging impacts are undoubtedly present in several watersheds.

   The cost of an integrated project on the central coast was estimated to be upwards of $500K. The major partner would be the Province, but the interest of industry in central coast stocks was noted.

2. *Enhance present work related to the Fraser River model for temperature effects on spawning success.* Sockeye stocks in tributaries to the upper Fraser River have been affected during their upstream migration by a combination of adverse flow conditions and temperature in the main stem of the river. Serious pre-spawning mortality of sockeye occurred during the 1999 return migration, with mortality of the Upper Stuart stock being in the range of 70%. Work in the Region has been underway for several years to improve a salmon habitat model that forecasts effects of changing river conditions on pre-spawning mortality and reductions in hatching success. The model has been developed and used to guide in-season management decisions, and it could also be used with the output from at least two GCMs to examine the future of upper Fraser sockeye under the probable range of precipitation and temperature conditions. A one-year project for this work was funded by the CCAF later in May.

Marine Ecosystems

There is good evidence that conditions in the marine environment have changed substantially in the last 25 years. The 1976 regime shift was followed by a second in 1989/90, and may have been followed by another in the late 1990s. Declines in salmon stocks in the south and central coast areas of BC have been linked to changing ocean conditions, and two explanations have been developed to link changes in abundance to climate conditions.

1. *Linkage to the Aleutian Low Pressure Index.* The climate system exhibits a number of dominant states, or regimes, in which the coupled ocean and atmosphere reside most of the time, with relatively rapid transitions between states. Climate change is expected to alter the length of time that the ocean spends in different regimes. If salmon stocks continue to respond to changes in the Aleutian low-pressure index in the way they appear to have done in the past, climate models indicate that average production will be better than it is today.

2. *Linkage to temperature of the ocean surface layer.* Ocean models indicate that the warm-water isotherms for salmon, which vary with season as well as with species, will shift significantly northwards as the climate warms. If the response of salmon to temperature in the future looks the same as it does today, their range in the North Pacific could contract dramatically.

It was noted, however, that the linkages through which CVC affects BC fisheries still need to be confirmed.

Future work might lie along two avenues:

- Continuation of observational research and retrospective analyses;
- Enhancement of efforts to develop ecosystem models that incorporate biophysical links to major climate variables.

Ecosystem modelling. Participants concluded that a dynamic ecosystem model analogous to the East Coast CDEENA project should be developed for the west coast of Vancouver Island. The work would reinforce an ongoing priority, integrate the work of several scientists, and provide support a longer term input for stock assessment (see Topic Session C).

Conducting this work with post-doctoral fellows or new, young scientists could have the advantage of entraining the very considerable expertise in ecosystem modelling at the UBC Fisheries Centre. The industry is also interested in involvement from the outset, and partnerships could be developed with the US National Marine Fisheries Service. Costs would range upwards from $250K.

Adaptations

Fisheries resources on the West coast are changing, and the industry is already responding to keep pace. The Department's domestic licensing policies, which restrict license holders geographically, are in tension with the projected northwards shift of species distributions. At the same time, climate change may bring new opportunities for the industry in BC in the form of new species (e.g., tuna) or in the way catches are sold and processed. Warmer waters, pressure on southern resources, and species shifts northwards may all conspire to add to the pressure to provide access to north coast shellfish resources.

At the same time, the principles of equity embedded in international treaties for the west coast should be reviewed from the perspective that fish distributions appear to be shifting northwards, consistent with the implications drawn from climate models.

Participants concluded that research should be undertaken to develop a strategy for incorporating shifting north-south distributions into domestic licensing policies and international treaty considerations.

The Province and the industry are both expected to have a strong interest in such a project. Cost is expected to be upwards of $150K.

Stewardship issues for the central North Pacific were discussed. There is a clear requirement for monitoring change in international waters, to which Canada has contributed in the past. High seas fisheries have implications to domestic species management. The scientific aspects should continue to be addressed through PICES and the management aspects through other international bodies.

Additional Information

While the present report was in preparation, the Canadian Centre for Climate Studies (CICS) published the proceedings of their workshop on "Sustainable Seafood in a Changing Climate" (www.cics.uvic.ca/workshop). The CICS workshop focused on supporting the adaptations required in the BC fisheries and aquaculture sectors. The major points to emerge in the proceedings were:

- BC fisheries have already been affected by climate change, whereas the aquaculture sector has not been.
- Impacts research priorities identified were:
  - how marine life adapts to changes at various time scales,
  - non-salmonids,
  - growth and mortality factors,
  - causes and life cycle timing for the changes seen in salmon.

- Scientists must “develop a detailed understanding of the consequences of climate change to oceanic and freshwater ecosystems and to the individual species living within them”.
- The fisheries and aquaculture industries need analyses of the repercussions of climate change scenarios at regional and local scales.
- The fishing industry is looking for leadership in developing adaptation strategies.

Region Session (B): ***ARCTIC & NORTHERN, INCLUDING HUDSON BAY***

(Chair and Reporter: Rob Stewart)

Participants: Don Cobb, Denis Gilbert, Rob Macdonald, Savi Narayanan, Jim Reist, Jacques Gagné, Yvan Simard, Rob Stewart, Pam Kertland

Participants discussed issues affecting impacts research in the North and the opportunities to build on partnerships. An approach to filling information gaps was developed.

Five major geographic areas were covered in this workshop: 1) Beaufort Sea, 2) Arctic Archipelago, 3) Foxe Basin, Hudson and James Bays, and Hudson Strait, 4) Baffin Bay and Davis Strait, and, 5) Inland freshwaters (e.g., Mackenzie River, Great Slave and Great Bear lakes). There are both physical and biological boundaries between these regions.

The session began with participants noting that the important issues had been well covered during the morning's presentation by Jim Reist (see the extended abstract elsewhere in these proceedings). Briefly, these were:

- Biological processes in the North have important differences from those in southern Canada
- Climate change is predicted to be the greatest in northern latitudes, but CVC effects are only one of several sources of change facing people in the region.
- The effects on biota will be mostly indirect, resulting from changes in habitat characteristics

The group noted that not only are changes apt to be greater in the north, but that those changes would also influence changes in southern areas, and that the north could serve as a predictor of future changes in the south. Transition/marginal species, such as harp seals, snow crabs, salmon, killer whales, can be used as "sentinel" species for distribution changes. Monitoring early invasions would provide information about the species that may be pre-adapted to cope with environmental changes.

The biological role of estuarine habitat will be greatly affected by shifts in the timing of the onset and breakup of ice cover. Ice itself is an important habitat for marine mammals, a highway for hunters and fishermen and the home to about 15% of total primary production. Polynyas are a special and sensitive habitat.

Participants noted that the most obvious effect to measure will be the predicted northwards expansion of the range of warmer-water species. The major rivers draining into the Arctic basin offer viaducts for freshwater species to move northwards, and ocean warming may result in the entry of new species from the Atlantic and Pacific (e.g., salmon). While fisheries in the region are trivial in terms of their economic contribution, they are of great cultural importance.

Field work in the North has the reputation of being expensive, due in no small part to travel and shipping costs, and the distances to be spanned. It was pointed out that some types of work can be carried out at the same costs as for the rest of Canada. Also, budget constraints and northern cultures have combined to produce an extensive partnership network. Partnerships are an integral part of working in the North, linking scientists with hunters, fishermen, teachers, ecotourism operators and others. Ships of opportunity can be used to reduce field costs, and community boards and treaty organisations can be used to help coordinate activities and reduce costs. Other DFO research programs, such as the Arctic Science Planning Initiative (ASPI) and stock assessment activities, can provide useful information. In particular, ASPI has produced a report with considerable detail on the requirements for CVC work in the Arctic. Studies by other agencies (e.g., the stomach contents of birds, and harvest studies conducted by land claims organisations) can provide additional insight into changes in fisheries resources.

Three approaches can be used to gain insight into CVC effects:

1. *Desk analyses*, in which biological or fisheries data can be linked retrospectively to climate parameters. As a starting point, one or two post-doctoral fellows could be hired to compile data, document and assess species distributions, and describe habitat preferences for key species based on existing publications. This task would likely take a couple of years, and can be represented by the matrix below:

	Data compilation	Species distribution	Habitat preference
Hudson Bay, James Bay, Foxe Basin			
Beaufort Sea			
Arctic Archipelago			
Eastern Arctic			
Inland freshwaters			

   The annual costs would be relatively low, in the order of $150K.

2. *Word models* can be developed to gain insight into the probable response of key species to changing climate parameters based on existing habitat preferences, as part of the desk analyses. These models can be expanded, as knowledge permits, into more quantitative estimators of change.

3. *New data* can be collected for northern fisheries indicators: marine mammals, Arctic char, Arctic cod, capelin, sandlance, and benthos. Data gaps related to the habitat preferences of these species at various life stages need to be filled to improve models of CVC effects. Changes in species composition and changes in distribution should be monitored in each of the five geographic areas.

The overall budget for a comprehensive CVC program in the North is large, reflecting the gains that need to be made in basic science as well as impacts. The workshop estimated that about $2500K would start a comprehensive program.

Region Session (C): ***INLAND FRESHWATER***

(Chair and Reporter: Ken Minns)

Participants: Ken Mills, Ken Minns, Michael Turner, Kevin Murphy, Roger Street, Brian Shuter, Jeff Curtis

Session participants discussed the goals for a regional program to identify CVC effects, and identified some of the biological and environmental issues that should be addressed. A study approach was developed around clusters of work areas, and an approach to funding and implementation was discussed. A phased program was recommended.

Regional Goal

> *The major goal should be to ensure that there is a significant freshwater component in DFO's climate impacts program.*

While inland fisheries management is delegated to the Provinces, provincial governments have repeatedly said that they expect DFO to support the research needed for fisheries and fish habitat. A freshwater program should consider all types of species together, and should effect coordination to overcome jurisdictional and regulatory boundaries.

Biological Issues

There are important differences between freshwater and marine environments when it comes to CVC impacts. While temperature in both environments is expected to increase, the overall volume of freshwater is expected to decrease. Changes in the timing of precipitation and runoff will affect life history stages. There is a better awareness in freshwater systems of such co-factors of climate change as the effects of uvB radiation on primary production and reproductive success in fish. Freshwater habitat has been more severely influenced by other human activities, especially in the south, causing habitat loss and destruction, species introductions and invasions, over-exploitation, acidic deposition, eutrophication and chemical contamination.

The distributions and thermal preferences of many freshwater species are known, and a start has been made at determining species responses to climate change. Thermal limits for some species have been used to forecast northwards shifts in distribution. Although species boundaries are geographically constrained by watershed boundaries, range expansions will occur northwards along rivers in response to temperature change. The migration of lotic species may be more limited. There is also an anomalous distribution pattern for freshwater species, essentially range undersaturation, in northern Quebec due to the relatively short time since deglaciation. CVC programs will need to look at both variability and change with landscape, human activities, and geological history as contexts.

Organisational Issues

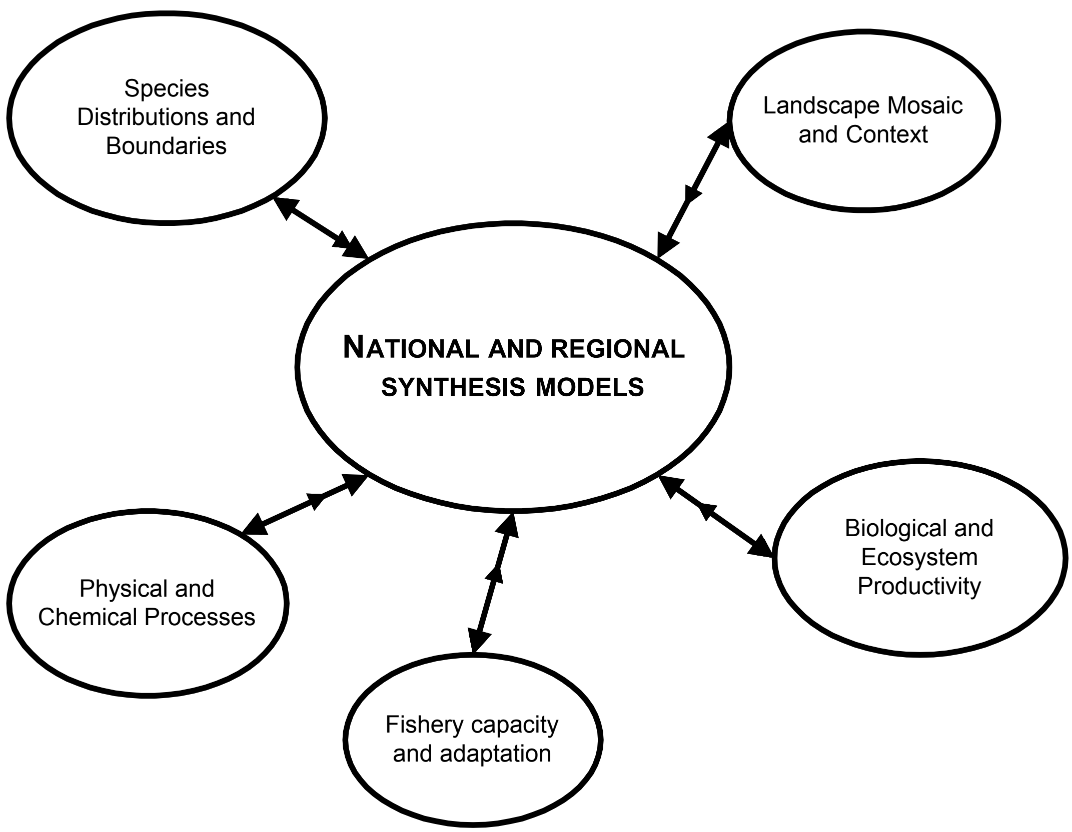
DFO and post-secondary institutions together carry out much of the freshwater research in Canada. The Provinces have a limited capability for research but can contribute a considerable body of fisheries management data and information. Other interested groups include NGOs, industry organisations, First Nations, and other stakeholders.

Coordination and networking will require a real effort. No single group or agency can undertake the range and scope of studies needed with DFO taking a central role. To begin with, linkages between partners need to be developed. With a framework for cooperation in place, a phased approach can be made to the needed scientific studies. Participants felt that the approach used in Canada for the LRTAP impacts program should be reinvigorated for CVC purposes.

Approach to Developing Case Studies

Workshop participants discussed a set of five study areas, clustered around a central element of national synthesis of the regional elements (see figure below).

Nodal Framework for Assessing CVC Impacts and Adaptation in Freshwater Fisheries



A node concerned with species distributions would set out by investigating how to detect and model changes in distribution (e.g., the northward invasions that are expected). A landscape/ mosaic node would work with the context in which species distribution occurs, including considerations related to geology, morphology, and human influences. A node concerned with fishery utilization would be concerned with adaptation and the users of the resource. The node for biological and ecosystem productivity would aim to understand the linkages between physical processes and the functionality of responses.

Comparative studies should be done where long time-series of data are available, taking advantage, for example, of the ELA, Turkey Lakes, and other EMAN lakes, streams and rivers in Ontario and the Prairies, and larger ecosystems like the Great Lakes.. There will be transfer off models and data among nodes with a technical steering group needed to ensure the coordination and integration of effort.

This framework would be applied regionally and nationally with networks of participants taking on pieces of the overall program. This will ensure comprehensive coverage of Canada's freshwater fisheries resources and facilitate the coordination of freshwater and marine components for anadromous species like Atlantic and Pacific salmonids.

Approach

A phased approach to implementation was recommended:

- Approximately $50K in 2000/01 to set up the central planning for the system.
- Then about $250K in 2001/02 to set up networking (e.g., through workshops) and to coordinate plans nationally and between departments.
- Full program implementation would require probably $2M/y over four years in incremental costs

The implementation resource requirement is on roughly the same scale as the resources for the LRTAP impacts program, where experience indicates that it might leverage perhaps 2-3 times that amount from other sources. It should be noted that the LRTAP program only covered eastern Canada whereas national coverage is required for CVC impact studies.

Region Session D: ***ATLANTIC COAST AND GULF OF ST. LAWRENCE***

(Chair: Bob Rutherford Reporter: Martin Castonguay)

Participants: Brad de Young, Denis Gilbert, Ken Frank, Ken Drinkwater, Glen Harrison, Martin Castonguay, Paul Keizer, Bob Rutherford, Denis d'Amours, Fred Page, Gary Lines, Alida Bundy, Brian Dempson, Michel Harvey, Yvan Lambert, Yvan Simard.

Participants focused on case studies, noting that while monitoring activities are essential they would not be considered during the workshop.

Retrospective Analyses

There was general agreement that the hypotheses put forward in Frank *et al.,* 1988, should be revisited, and should be tested where possible. This exercise was seen to be at the core of the regional program. Three approaches were suggested:

- Data mining of fisheries and other data
- Backwards looking workshops similar to the one recently held by ICES for cod
- Runoff predictions should be updated from the most recent model outputs, although it was noted that the resolution of precipitation outputs was poor. This topic is especially important for inland seas.

Biophysical Models

Biophysical models are important tools for three purposes:

- to help identify critical data gaps;
- to help fill in missing information, and
- to develop the "plausible futures" discussed earlier in the workshop

Studies of Species Distributions

Species distribution is the most important aspect of CVC change to monitor, and the results can be made available relatively easily and quickly. There is a need to pull out what is available on the short term, such as David Brickman's work on biophysical modelling, or the work on comparing distributional changes across cod stocks. The distribution of all levels of the marine ecosystem should be tracked to identify northwards shifts, including for plankton, at least two species of commercial and non-commercial fish, and marine mammals. This proposed focus on distribution is very similar to the focus in forestry and agriculture.

Distributional studies should be linked with other programs. For example, the ECNASAP database, which is an international stock assessment database for the North Atlantic, should be helpful in identifying movements northward. A matrix should be constructed to associate biological data with T and S. Lab studies should also be undertaken to determine physical sensitivities.

Scientists have to tease out the 1st order (direct) and 2nd order (indirect) effects of climate change from those due to other causes. An example of a 1st order effect is the effect of decreasing ambient temperature on the physiology of an organism, while an example of a 2nd order effect may be trophic effects, i.e., those mediated through the food web. Looking at large-scale features (e.g. N/S circulation on the Labrador Shelf, freshwater input in the Gulf of St. Lawrence) and ecotones by focusing on organisms that drift (e.g., plankton) may be useful as well.

Productivity would be another important parameter to monitor, but the problem is not as easily tackled as species distribution and CVC studies can be put off until later. Continuous plankton recorder data from ships-of-opportunity can be used to identify major shifts in dominance and species composition. These data are being made continuously available.

Resource Requirements

As a first step, DFO should pay to update Frank *et al.,* and to validate or test its hypotheses, where possible. The most important organisms to address are cod, snow crab, salmon and plankton. The update and testing could be done in a two-year period, for about $50K per year.

Studies beyond this could be funded by the CCAF. Each DFO region could include perhaps two or three proposals in a package for the East coast. Three topics were recommended:

- to examine the temperature dependence of cod and haddock production on the Scotian shelf,
- to look at the effects of CVC on snow crab distribution, and
- to update and analyse recent developments in the effects of CVC on cod stocks

While much collaboration between DFO and universities still takes place, the rules of the game are changing. It was noted that NRCan is holding workshops to establish regional climate change networks across the country. The Atlantic Region workshop was being held at Mount Allison University, and DFO participation was invited.

Confidence in the Interpretation of Global Warming Impacts Will Improve Confidence in Management

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Fisheries biologists now accept that climate and climate change can have important impacts on the abundance trends of commercially important fishes. This is a significant change in the thinking that fluctuations in abundance were largely a result of fishing impacts. Once climate is recognized as a factor in fisheries management, it is apparent that density-related impacts on Atlantic and Pacific salmon survival occur in the ocean. For Pacific salmon this means that the management of stocks is not confined to regulating escapements. It also means that persistent trends in climate or regimes should parallel persistent trends in productivity. We know that the persistent trends in Pacific salmon productivity follow trends in the Aleutian low. A recent model of the trends in the Aleutian low using two global warming models showed that there would be a change to more frequent or more intense lows as atmospheric carbon dioxide increases. As there is an accepted relationship between intense lows and increased salmon production, these models would indicate improved salmon production. This observation is different from an interpretation made using sea surface temperature projections, indicating the need for caution in the interpretation of impacts using these model results and the urgency in conducting the appropriate research.

Comparative Dynamics of Exploited Ecosystems in the Northwest Atlantic: Overview and Climate Impacts

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The aim of this project is to analyse changes in the structure and function of NW Atlantic shelf ecosystems and to determine how these may have affected the productivity of living resources. This project has defined a framework for analysing and modelling marine fisheries ecosystems in Atlantic Canada. Work is now being conducted, both as part of the project and independent of it, to address the data and analysis needs within that framework. Several modelling approaches are used (both mass-balance and dynamic models) to answer questions about how these ecosystems are structured, their dynamics, how these may have changed over time and space, the effects of environmental variation, predation, and fishing, and the implication of these changes for our fisheries. Several Atlantic coast ecosystems are being modelled and we focus on three time periods to capture key temporal differences in these ecosystems, for example, pre and post groundfish collapse. This broad-scale approach provides a quantitative framework for synthesising available information on basic ecosystem structure and function. Inconsistencies in model fits, either within or between ecosystems, will serve to identify processes or influences, both human and natural, which might otherwise go unnoticed. In parallel, we are identifying and filling critical gaps in our database with field programs. New information is being generated by CDEENA and other projects for these models and syntheses of new and existing data will include a large data set of fish and marine mammal diets, a suite of catchability estimates for research vessel surveys and biomass estimates for many species not routinely assessed for fisheries purposes. At projects end, we aim to be able to answer the question: "*What have been the relative effects of environmental variation, predation and fishing, and their interactions, on the population dynamics of marine finfish and shellfish inhabiting shelf ecosystems of the Northwest Atlantic?*"

Uncertainty and Risk: Implications for Forecasting and Management

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The uncertainties inherent in the ocean environment are legendary, ranging from the short-term vagaries of the weather to medium-term fluctuations of fish stocks to longer-term uncertainties involved in upwelling and other oceanographic phenomena. Climate change is clearly a major source of uncertainty, one that implies risks of particularly large-scale undesired outcomes. How can forecasting efforts and management initiatives incorporate climate change, and other similar processes? How can sustainability and resilience be enhanced, in the face of large-scale global change processes, and the uncertainty and risk inherent within those processes? What are the research implications? This presentation explores such questions within the context of the ocean environment, drawing on the recent report "Canadian Marine Fisheries in a Changing and Uncertain World" (deYoung *et al*., NRC Press, 1999), commissioned by the Canadian Global Change Program of the Royal Society of Canada.

The presentation begins with an overview of major processes of change in fisheries, ranging from physical environmental processes to economic and sociopolitical ones. With respect to climate change, the challenge of forecasting arises at several stages: (1) climate change itself, (2) related physical changes (e.g., sea level, ocean temperature), (3) biological implications (e.g., changes in primary productivity), (4) direct impacts on human uses (e.g., fishing, tourism, ports), and (5) induced impacts on human society (e.g., social, economic, community). At each of these stages, uncertainty can arise in forms ranging from randomness to parameter and state uncertainty to structural uncertainty. In all these cases, there is a need for risk assessment and risk management procedures. In addition, it is important to approach uncertainty, and notably the challenge of structural uncertainty, through a combination of (a) precautionary approaches to management decision making, and (b) pursuit of fishery resilience through 'robust management', re-designing the management system so that it can better provide acceptable results even if our understanding of the fishery system is incorrect.

Climate Change Impacts and Adaptations Science – Needs of the Commercial Fishing Sector

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The west coast fishing industry has a wholesale value near $1 billion, including salmon aquaculture. Approximately 200 processing plants in BC produce 16,000 full time jobs, many in coastal areas of high unemployment. The industry is an important generator of foreign earnings; about 90% of production is exported.

The industry is changing in important ways. While the salmon catch is declining, the harvest of shellfish and groundfish is increasing. There have been reductions in fleets and plants, overhead, and operating costs. There is increased emphasis on value added and on outsourcing, especially from Alaska. Processors and harvesters have diversified away from reliance on salmon.

The industry has taken several steps to control the impacts of fishing. It has moved away from competitive fisheries. The duty of individual skippers to fish responsibly is being emphasised. Selective fishing measures are being adopted. The number of licenses in the salmon fleet has been reduced to 37% of 1995 levels. Further progress depends on better understanding where and how fish live, and here the demands of climate change research might coincide with those of fisheries management. The shift from single species management to ecosystem management demands greater understanding of the factors that determine abundance and distribution.

We have to be able to separate the effects of natural variability from those of climate change. Research on climate and fisheries issues should be integrated. There is no consensus that the climate-related events we have seen are a trend. They may be cyclic, and the cycles may again be changing in favour of productivity. Although both climate change and fisheries management have become highly politicised topics, it is important to remain objective, and to avoid extreme applications of the precautionary principle. Application of the precautionary approach should be based on sound, integrated research.

The commercial fishing sector has several needs if it is to adapt successfully to the changes ahead: 1) Some ability to foresee resource trends at a decadal scale in order to make informed investment decisions. 2) As clear an understanding as is possible of factors affecting stock strength and diversity, in order to design sustainable fisheries. These factors include the sensitivity of fish to change, risk identification and management, identification of stable TACs for groundfish and herring, better knowledge of the implications of mixed stock fisheries for salmon, and good research, especially to support international obligations. 3) As much information as is possible about non-fishing impacts on the environment, especially those arising from urban growth, industry, and conflicting water use. Good research is important, but climate is only one of the stresses on salmon in freshwater. Recent problems seem due to a combination of extreme weather events and habitat degradation. The industry must be included in the process to assess each of these areas.

Basic Science Needs

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In 1988 a report was produced by DFO scientists that described the changes in the fisheries of Atlantic Canada associated with global increases in atmospheric CO_2. In essence this was an impact scenario that projected plausible future states of the Atlantic marine ecosystem and associated continental shelf fisheries. Several generic recommendations or “needs” were made in the report that are still considered relevant. These include:

- close monitoring of species at the limit of their distributional range
- improvement of the limited information base that exists for opportunistic, ecologically important species
- continued characterization of size-spectra of fish production systems
- routine generation of data on fecundity, condition factors, and diet composition
- monitoring of inter-annual changes in stratification
- determination of life cycle events sensitive to environmental change
- integration of bio-physical data through simulation modelling
- detailed study of new predator/prey relationships established through range extensions (exotic species)

Examples were provided of recent developments that serve to reinforce the relevance of the past recommendations. The development of new, comprehensive data bases and recent results from research based on monitoring and modelling studies were highlighted. For example, the East Coast of North America Strategic Assessment Project (ECNASAP) has compiled most of the trawl survey data for the western Atlantic as well as data on seabirds, temperature and salinity, and sediments. The database covers the area from Cape Hatteras, North Carolina, USA to Cape Chidley, Labrador Canada for 1970 to 1994 and could be easily updated and expanded to other contiguous geographic areas. This type of database can be considered a model that other regions could attempt to duplicate for the purpose of developing regional specific impact scenarios. Recent modelling studies developed during GLOBEC I were also presented to illustrate their potential for coupling climate change to biological production.

Implications of Climate Change in Canadian Inland Seas

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The Gulf of Saint-Lawrence (GSL) and Hudson Bay (HB) represent the two largest Canadian Inland Seas. Both are seasonally ice-covered, large-scale estuaries that receive very substantial amounts of buoyancy forcing from surrounding river systems. According to presently available climate scenarios, the amount of continental runoff flowing into those inland seas would likely diminish in the future, possibly by as much as 40% for the St. Lawrence River. The implications of this reduction in freshwater buoyancy forcing combined with warmer air temperatures must be studied in detail in order to look at how the water masses and ice cover properties would be affected in the Gulf of St. Lawrence and Hudson Bay. To this end, work has already begun for the development of a regional coupled ocean-ice-atmosphere model under the joint leadership of René Laprise (UQAM) and François Saucier (IML), with coupling to a hydrological model of continental runoff envisaged as well. Their Regional Climate Model (RCM), although driven by a General Circulation Model (GCM) at its open boundaries, will have a much finer resolution than the GCM and will therefore output more realistic looking fields of wind, air temperature, precipitation, sea ice and water properties over these inland seas. The RCM results will be made available to climate change impacts researchers, and will form the basis of several studies on the likely effects of climate change on the marine ecosystems of the GSL and HB.

The very mild winter of 1999 and much reduced spring freshet that followed may have offered us a first glimpse at what would be a "normal" year in the warmer and drier climate of the future. The 1999 phytoplankton spring bloom occurred more than a month earlier than it did from 1995 to 1997. Moreover, preliminary results (M. Starr, pers. comm.) suggest that the average chlorophyll concentration from May to August was also higher than in the previous years. Moving up the food chain, we may also ask ourselves how the species composition of the large zooplankton community might change in response to climate change. Preliminary results based on cod stomach contents suggest that the colder than normal water conditions of the early 1990's were favourable to hyperiid amphipods, a possible competitor for food and/or predator of cod and redfish larvae (M. Harvey, pers. comm.). Would the relative abundance of these amphipods diminish under climate warming?

To determine the effects of climate change on key species of invertebrates and fish, we propose a three-pronged approach: 1) regular field surveys to monitor changes in the distribution and abundance of species in response to temperature/salinity/dissolved oxygen regimes; 2) controlled laboratory experiments to look at the temperature/ dissolved oxygen requirements of species and to study the growth, metabolism, food conversion efficiency and reproductive efficiency under a range of temperatures; 3) single-species or multi-species models of the effects of temperature on life history parameters and their impacts on population dynamics and resilience.

Information Needs and Adaptation in the East Coast Commercial Fishing Sector

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Climate change as an issue is not currently on the industry's radar screen. Consideration of the large natural variability in inter-annual conditions suggests that climate change considerations should be treated with caution. While species distribution patterns have obviously changed in recent years, the cyclical nature of these changes has not been fully resolved.

Scientific investigation of models and scenarios seems worthwhile, but a decision should be made about which model or models to support. The industry will find it confusing to be faced with differing results from several models, but it would be more desirable to see a range of scenarios for species 20 years out than to see single projections of species effects. This range should incorporate climate variability as well as change.

Sea level rise due to climate change will take place gradually. The industry will need to look at the implications for wharves and other infrastructure, although it will be difficult to protect wharves from wind and wave effects. Not all expected changes might be negative. The shellfish aquaculture industry is experiencing an improvement in plankton culture cleanliness thought to be the result of lower bacterial contamination due to UV effects.

Can genetic modification help stocks adapt to climate change? The potential power of genetic engineering approaches should be examined to see if they might form a part of DFO's adaptation research. However, resources would first need to be found for scientists to do a credible job of addressing climate change issues. The capacity to do this in the face of recent budget cuts is questionable.

Climate and Ecosystem Monitoring

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Broadly speaking, DFO is (or will be) engaged in two types of climate-ecosystem research, (1) one in which ocean ecosystems may actually modify the climate system, i.e. have measurable impacts on climate (GHG research) and (2) one in which the impacts are thought to be largely unidirectional, i.e. climate effects on ecosystem structure or function. The latter is the focus of this workshop. Much of the emphasis (and past discussion) has been on climate impacts either directly or indirectly on harvestable fisheries resources but current discussion has broadened to include ecosystem level response to climate change.

The mounting concern about climate change and impacts it will have on terrestrial and marine ecosystems has prompted the international research community to develop a globally coordinated observational system to monitor critical environmental and biotic properties that are part of and are affected by the earth's climate system. The ocean's component of this program is the Global Ocean Observing System (GOOS).

A brief overview of Canada's contribution to GOOS, and more specifically the Living Marine Resources (LMR) module of GOOS, will be presented.

Participation in LMR-GOOS planning at the international level and two national workshops have generated a conceptual framework that will facilitate the integration and enhancement of regional monitoring activities within DFO and will help rationalise and prioritise program elements.

Aside from meeting Canada's commitments to GOOS, this framework will be useful in developing DFO's research priorities related to climate impacts and adaptation.

A comprehensive monitoring program is only as good as our ability to interpret the ecosystem changes we document. It will be essential to develop and adequately fund, in parallel with routine ecosystem monitoring, relevant research programs to provide the mechanistic understanding that will be required for forecast and prediction (e.g. Canada GLOBEC).

Climatic Implications to an Ecosystem Management Approach and Integrated Fisheries Management

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Single species management plans evolved to meet the demands of the commercial and regulatory sectors in the Maritimes. However, advances in the understanding of ecosystem effects on abundance are making it more cost effective to study the application of marine ecosystem research to fisheries management. Several considerations are involved in an ecosystem approach.

There are about 30 species committees and 65 management plans in the Maritimes. An ecosystem management approach is going ahead within the single-species advisory committee structure to which the industry has become accustomed. For the new strategy to work, the education of all parties is important. Managers, DFO staff, industry groups, fishers, and NGOs must all buy into the Integrated Fisheries Management Plans (IFMPs) now being developed. Specific ecosystem objectives are being set for individual species. An ecosystem management board and an ecosystem steering committee have been established. While a start has been made, it will probably take another year to implement this approach more fully.

Climatic considerations are just starting to be applied to fisheries management. Historically, adjustments to the effects of climate variability have been made retrospectively. As this became a problem in the early 1990s, two approaches evolved. The industry has become involved in surveying changes in ocean climate, and DFO has begun to make adjustments to fisheries management plans to incorporate climate information. Fishers are well placed to detect changing oceanographic conditions. The temperature information they provide gives an early warning of changes, and the industry data are incorporated into regional databases where they can be integrated with other data for a closer examination of events.

An example can be found in the Scotian shelf snow crab fishery. Snow crab are sensitive to changes in the strength and position of the Labrador current. Recent oceanographic conditions have created a temporary increase in biomass, but recruitment is expected to decline to more normal levels. The combination of declining recruitment and life-cycle limited biomass has created a unique situation. Allocations have been increased by a factor of four, but only by issuing temporary licenses. The idea is to deliberately fish down the temporary increase in abundance in a way that benefits the industry, but which does not lead to the entry of new long-term fishers into the industry.

Climate Change Issues for Northern Aquatic Ecosystems

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The impacts of climate change for Canada are predicted to be greatest in arctic regions. Given the size and diversity of the area, substantial regional differences will almost certainly occur. Temperature will rise generally, precipitation will shift both in terms of amounts and seasonal distribution, and the variability of these parameters will also shift. In addition to climate change, ozone depletion and the related increase in incident ultraviolet-B radiation will be greatest in the north. All of these factors will significantly affect the biotic components of northern aquatic ecosystems and may result in substantial change from current situations.

In comparison to ecosystems in southern latitudes, the northern regions of Canada are characterized by: low productivity which is extremely pulsed during a short season; low rates of energy transfer between components of ecosystems; lower diversity at the species level resulting in simpler systems (fewer steps and interconnections); high seasonal variability in environmental conditions; and, extremes of climate on spatial, seasonal and inter-annual scales. A further defining feature of northern environments is the ubiquitous presence and persistence of ice which is seasonally present on freshwaters (6-11+ months of the year), seasonally present as land-fast ice (8-11+ months), and present over many years as multi-year polar pack ice. Ice defines the north and is an important habitat for biota and humans. For example, sea-ice provides refuges from predators for small whales, is a habitat for polar bears and their primary prey - ringed seals, and in some arctic marine areas ice-associated algae account for up to 15% of total local primary productivity. From a human perspective, ice serves as a platform for both travel and harvesting. Finally, there is a general lack of long-term biotic databases and limited understanding of biotic processes in the north, both of which substantially affect the nature and direction of research.

Climate change must be recognized as one of several significant impacts on northern ecosystems and biota. Exploitation is at or near sustainable limits, especially for marine mammals and fish populations near communities. Rapidly increasing human population, and a desire to maintain and even increase natural resource harvesting will increase pressure on such resources. Moderate to high contaminant loadings in the Arctic will continue to be delivered through atmospheric processes and by drainage of large rivers to the arctic basin. Contaminants create concern for human health, impact biological populations, and cause energy to be diverted from biological processes such as growth, reproduction, and the maintenance of internal homeostasis. Also, industrialization and development are increasing in the north, bringing increased access to previously remote areas as well as local impacts of the activities themselves (e.g., mining, dredging, hydrocarbon activity, etc.).

From the perspective of most aquatic biota, climate change impacts will be primarily indirect. That is, because most aquatic organisms spend all or most of their life in water, the effects of climate change will be mediated through the aquatic habitat. The partial exceptions to this are marine mammals which, depending upon the species, spend varying degrees of time at the surface or on land or ice. Thus, to fully appreciate and understand the impacts of climate change to aquatic biota, both the direct effects of climate change on the aquatic habitat and the indirect transmission of these effects to the biota must be understood.

In assessing climate change impacts on northern biota and for developing adaptation strategies to those impacts, five general questions arise. 1) What are the impacts of climate change on northern fish and marine mammals, their habitats and aquatic ecosystems? 2) How important are those impacts to biology and productivity of the system, and in the overall suite of all impacts on the biota? 3) What impacts will occur on fisheries? 4) How do we balance conservation, sustainability and potential major impacts for harvested northern resources? 5) What adaptive responses are available to resource users and managers to deal with the impacts?

Although our present understanding of the potential impacts of climate change on northern aquatic biota is limited and primarily anecdotal, some specific impacts can be predicted. These include: colonization of northern waters by southern taxa (e.g., establishment of Pacific salmon populations in the western Arctic), ice-related impacts on polar bears and ringed seals, changes in productivity including both local increases and decreases, and contraction of the range and/or extirpation of native northern species. Thus, to truly address and predict climate change impacts to develop appropriate adaptation strategies, we need to conduct research in four areas. 1) Linkages between the northern biota and their habitats must be understood (e.g., what are the various thermal preferenda for Arctic char throughout life history). 2) Research must be conducted on how environmental parameters such as temperature and precipitation are mediated through aquatic habitats, how they affect non-biotic components and processes in the ecosystem, and how climate change is likely to affect these (e.g., water mass changes and their effects on nutrient fluxes, seasonal shifts in freshwater availability, predictability of environmental cues used by biota to trigger critical life history functions). 3) We must understand how key environmental parameters and changes in the habitat resulting from them are translated through effects on individuals to effects on populations of northern biota, and whether such changes will be positive or negative in terms of biomass (e.g., how are environmental changes linked to habitat changes such as altered nutrients, growth of individual fish, and ultimately productivity associated with harvestable surpluses). 4) To develop adaptation strategies, we must understand how climate change impacts on aquatic ecosystems are transmitted to fisheries and fishers, and the implications of this to fisheries management (e.g., access to fisheries, availability of new and likely initially rare species to fish, competing uses for fishery resources).

There are at least four approaches to investigating environmental and biotic interactions and the impacts of change in environmental parameters. First, retrospective analyses can relate biological or fishery parameters to environmental characteristics. Such analyses require long-term data for both the environment and the organisms ideally at similar levels of spatial and temporal resolution. The second approach correlates current biological scope to the environments occupied. For example, the range of environments occupied by geographically widespread populations of the same species provides insight into the possible responses which might dominate in a particular area under a changed climate. Third, experimental and/or observational studies investigate the direct association of environment and biotic response. Examples include determining lethal or productive limits of fish to thermal regimes, as well as long-term observations of effects of climate change itself. Experimental approaches require significant

resources and are typically limited to only one (e.g., temperature) or a few parameters for one or a few life stages. Observational approaches are handicapped by the requirement for long periods (e.g., years or decades) of consistent observation of both environmental change and biotic response. The fourth general approach can be loosely labelled as modelling and includes simple word models based upon generalized understanding through to predictive models rooted in quantitative understanding. Such modelling provides understanding of the scope and nature of future events although significant assumptions must usually be made hampering the precision and accuracy of the predictions. Furthermore, to be quantitative modelling requires inputs from the previous three approaches. Thus, assessing impacts of climate change on northern aquatic biota requires much work in the first three areas before realistic models of biotic response and subsequent human adaptation options can be developed.
Specific steps for assessing impacts of climate change on northern fish and marine mammals and the ecosystems upon which they depend must precede development of an adaptation strategy. Thus, the first critical step is to develop knowledge on the linkages between aquatic biota and key environmental parameters expected to change in the future. The ultimate goal should be to model the relationships accurately and thereby predict the biotic responses to seasonal and life-long environmental features and changes in such parameters. To link predicted biological responses to plausible scenarios of climate change, better regional and local scale models of environmental change are required. These must include expected change, limits to the change, and pattern and temporal (i.e., seasonal and annual) variability of important parameters such as temperature, precipitation, and incident radiation (including uv-B). For northern aquatic ecosystems such environmental modelling should be conducted on the basis of natural ecosystems (e.g., drainage basins for rivers, seas and bays for the arctic marine ecosystem).

Understanding derived from the biotic-environmental linkage and the regional or local models of climate change would then be used to develop adaptive (i.e., responsive in the short-term) management responses. The goal is to balance all major impacts to ensure conservation of the biota, sustainability of fisheries, and traditional life styles of northern peoples. Flexibility in fisheries and fisheries management must be maintained, capacity for rapid responses must be maintained, commercial fisheries should not be over-capitalized, and above all a biological buffer must be maintained for all fisheries (i.e., fish conservatively). Flexibility in scientific research must similarly be maintained to be able to respond to new complexities, for example, rapid response to changes in species compositions.

Finally, climate change is an experiment in progress and to derive the greatest benefit of knowledge from the experiment, regular monitoring of the progress and adequate research into the processes governing aquatic ecosystems must be conducted. Similarly, anomalous events especially those signifying ‘regime shifts’ (i.e., step-wise change vs. gradual change) must be accurately documented. Ways of doing this include routine well-funded basic science, appropriate monitoring programs including those conducted by local people, sentinel fisheries and research conducted in key areas. Given the spatial extent and environmental diversity of the Arctic, the approach outlined here needs to be conducted for critical systems and biota for at least five general areas: 1) Beaufort Sea, 2) Arctic Archipelago, 3) Foxe Basin, Hudson and James bays and Hudson Strait, 4) Baffin Bay and Davis Strait, and, 5) Inland freshwaters (e.g., Mackenzie River, Great Slave and Great Bear lakes).

Climate Impacts in the Freshwater Environment

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The surface area of Canadian freshwater environments (lakes and rivers) exceeds Pacific territorial waters, and the economic value of freshwater fisheries rivals that of all marine fisheries. It is useful to contrast potential impacts of climate change on freshwater and marine environments - in both, the supply and character of water will be affected. Many freshwater environments will shrink as water supplies decline, while rising sea levels will ensure that marine environments expand. Water temperatures are likely to increase in both freshwater and marine environments. The combination of decreasing water supply and increasing water temperature in many freshwater environments makes assessment of overall impacts on aquatic resources difficult: declines in the overall volume of freshwater habitats must negatively impact potential standing crops, but increases in water temperature may positively affect specific rates of production for some organisms.

Impact projections that provide a credible synthesis of these opposing effects must account for regional differences in geography, geomorphology, ecosystem structure, fish community structure and expected changes in climate. Impact projections of changes in fish zoogeography are less problematic since they are founded largely on assessing tolerance of changed abiotic conditions rather than estimating changes in biological productivity. Freshwater environments are particularly suited to assessing impacts of climate change on fish zoogeography because: (i) in freshwater environments, geophysical barriers to distributional change ensure that current zoogeographic boundaries reflect relatively long term, average climatic conditions;(ii) current distributional boundaries of most North American freshwater fish are known; (iii) the thermal preferences and temperature sensitivities of many of these fish are known and have been used to group species into three thermal guilds (cold water, cool water and warm water); (iv) guild membership is linked to the seasonal timing and temperature sensitivity of the critical life history processes (spawning, growth, winter behaviour) that can determine zoogeographic boundaries; (v) geographic isolation of many populations to small local regions (e.g. individual lakes) makes it reasonable to associate fine scale local climatic conditions with population-specific life history characteristics, thus making comparative studies across climatic gradients effective and informative.

Case studies exist for several freshwater species (e.g. yellow perch, smallmouth bass, brook trout) that illustrate the kinds of mechanistic models that can be used, both to explain the position of current distributional boundaries and to forecast boundary changes due to climate change.

Impacts and Adaptations Science Directions

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Adaptation involves spontaneous or planned action taken to adjust to potential or actual climate conditions. It is the process through which the effects of climate on health and well-being are minimised. The information now available to government has helped enable international negotiations, but it is insufficient to allow determination of what emissions levels constitute "dangerous" intervention in the climate system. Progress depends on: (1) improving confidence in projections of future climatic conditions; (2) improving confidence in projections of climate change impacts; (3) improving confidence in the adaptation process; and (4) communicating the results to Canadians.
Our confidence in elements of the climate system varies. Projections of global mean temperatures and sea level rise are thought to be fairly accurate, while projections of ocean circulation changes and thresholds in the climate system are much less so. It follows that impact projections associated directly with temperature and se level rise are the most certain, while those related to changes in ocean circulation need to be informed by improvements in climate science as well as in impact research.

Adaptation strategies should be based on the state of knowledge about climate change science and climate impacts research. Assessing the degree of certainty in both areas together provides insight into the actions that should be undertaken and the work that should be planned. For natural resources such as Canada's fisheries, adaptation strategies can be planned and implemented early if they can be linked to areas that are well understood, e.g., the effects of temperature. Where impacts are less certain, e.g., the effects of changes in precipitation or of extreme events, a better approach would be to minimise vulnerability in the human system and to monitor impacts. Where uncertainties are greatest, e.g., where effects would depend on changes in ocean circulation, worst case scenarios should be evaluated, monitoring triggers should be set, and additional information should be secured.

Several actions can be taken to minimise future adaptation to climate change effects in the fisheries. Many of these actions involve a common-sense approach to reducing the effects on fish and fish habitat due to other stresses. Additionally, some flexibility should be negotiated into international fisheries commitments to allow room for changing species distributions.

Making progress on impacts research involves better understanding the sensitivities of physical, biological, and human systems. Characterisation of the climate system, impacts modelling, and other approaches to helping systems adapt are all required. Canada also must undertake research to improve processes for identifying and evaluating the viability of adaptation options. National syntheses of knowledge from different sectors and regions of the country are needed to inform decision-making and provide advice to Canadians.

Science Needs and Scenario Development

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The largest impacts of climate change and the greatest need for adaptation strategies will arise in situations where the effects on natural resources are large and the capacity to adapt to changes is small. Scientists need to investigate both how climate and ecosystems will change, so laying the foundation for work with resource sectors and other sectors of the economy to help them adapt.

Basic national climate change scenarios will be provided through the Canadian Climate Impacts Scenarios Project (CCISP), which is being funded through 2001 by the CCAF. The third report of the IPCC defines a climate change scenario as: "a plausible future climate that has been constructed for explicit use for determining the impacts of climate change on environmental and resource systems of importance to human society." The CCISP has several related aims: (1) to provide basic national climate change scenarios; (2) to develop a nationally consistent framework through which sector- and region-specific scenarios can be developed; (3) capacity development; and (4) engagement of university scientists and users in scenario development.

The CCISP is managed by the Canadian Institute for Climate Studies (CICS). It will provide the basic climate change scenarios for Canada, based on GCM resolution (3.75 degrees latitude). The scenarios being made available are based on three greenhouse gas experiments and an experiment with sulfate aerosol forcing. Three time slices are available for comparison to the period 1969-90: the 2020's 2050's, and 2080's. Monthly, seasonal, and average means are available for these three future periods and the decades on either side. Mean, minimum, and maximum temperature, precipitation, a radiation variable, a humidity variable, and wind speed are interpolated to 0.5^{o} resolution. Sea level, sea surface temperature, and sea ice are among the variables being added to the model outputs. Scenarios from the international GCM community are also available, along with a baseline climate data set. Some material is already available on the internet, in keeping with the objective of communicating timely results to users.

Long control simulations have been undertaken at various modelling centres to simulate 'natural' climate variability. Comparison of the scenario outputs with this natural variability will allow the significance of global change to be calculated. While global models agree generally on the direction of changes, GCMs reproduce different aspects of the historic climate with varying degrees of accuracy. Impacts scientists should use the output of at least two models as the basis for their projections, and should model impacts based on the available range of plausible futures.

The CCISP will also facilitate a number of workshops examining the construction of scenarios for different applications. A workshop on methods and techniques for constructing regional climate change scenarios will be held this fall, and a workshop specific to marine and coastal implications is being planned.

Global Warming and the Prospects for Fisheries Management

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Global warming is expected to cause massive changes in the environment as a result of increasing greenhouse gas levels. Most scientific discussion has focussed on assessing the degree of climate warming that may occur or evaluating the potential effect of specific global warming scenarios on important resources. However, the magnitude of the probable temperature increase and the rapidity with which it is expected to occur are outside of society's previous experience. I believe that the likely impacts on fisheries that will result are also outside of our capability to successfully manage. We now know that the changes in northern hemisphere temperature occurring in this century, and which are generally consistent with the projections from global warming models, are on a scale unprecedented in the last 1,000 years. The rapid changes in warming in this century relative to the previous nine centuries are, however, trivial compared to the rate of change that global warming models project for the near future. The events currently taking place are also outside of the recent evolutionary experience of fish populations as well, so we can reasonably conclude that most existing fish populations are going to be ill-adapted to climatic conditions that have not been experienced in over a thousand years. If climatic changes anywhere near projected levels occur they will, I believe, prevent fisheries scientists from being able to function effectively in providing credible assessment and management advice in a sufficiently timely manner to prevent major fishery collapses. In summary, mild global warming is already here, and there are reasons to be deeply concerned. Within the fisheries community it is time to begin the debate about whether we can successfully manage fish resources under climate change, and not wait until "better" scientific models arrive. For reasons that I discuss, acceptably good models of future climate are not scientifically possible, and making the extension to impacts on aquatic resources is even more tenuous. Waiting will not resolve these limitations. It is time to begin doing a serious job of explaining to policy makers and politicians why we are likely going to be unable to deliver on our professional responsibilities now, rather than later, when global warming will just be an excuse.

APPENDIX 3. BACKGROUND REPORT FOR THE WORKSHOP “*CLIMATE CHANGE IMPACTS AND ADAPTATIONS SCIENCE: ACTIVITIES AND NEEDS IN DFO”*

Executive Summary

This report takes an inventory of climate change Impacts and Adaptation science projects underway in the Department of Fisheries and Oceans. It also lists and evaluates future needs, on the basis of source material and telephone interviews with selected staff of Science Branch, Canadian Coast Guard, Natural Resources Canada, Environment Canada, and universities. The review takes place in the context of an active climate change program in DFO, which is linked outwards to other Departments, upwards to international programs, and downwards to regional issues.

Every region of the country has at least some activity underway to evaluate the sensitivity or vulnerability of coastal and marine ecosystems to changes in one or more climate variables. While a significant part of this work is taking place around the fringes of stock assessment, many projects can be identified as falling within the scope of Impacts science (see Page 2 for clarification of this term). The Impacts science projects are, however, concentrated in three regions of the country: Pacific, Laurentian, and Maritimes.

In contrast, the Department is still on the ground floor in building an Adaptation science program. Very little work is being done with communities and business sectors to help them characterise the implications of the range of conditions foreseen by the Canadian Climate Program, and adapt their operations accordingly.

Given all of the needs identified, there is a real risk that DFO could spread itself too thinly by tackling too many problems at the same time. A focussed approach is needed, for which a first step might be to cluster the requirements by region and by scope. A limited set of needs, linked by scope and linked nationally and internationally, would provide the Department with a framework for the next phase of Impacts and Adaptation science.

Future work should address three elements important to DFO:

- Basic biological research, where the need has been determined from the hints provided by scientific insight, retrospective analysis, and statistical, mass balance, and numerical models.
- Biological modelling and other work whose purpose is to help determine the sensitivity and vulnerability of ecosystems (i.e., Impacts science).
- Work to convert a range of impact scenarios into economic and social effects, and then to help communities and sectors adjust to the changes foreseen (i.e., Adaptation science).

None of these three areas can prudently be neglected, implying that DFO should develop a scheme for apportioning the available resources.

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Introduction

DFO has been active in the area of climate change science since the First World Climate Conference, held in 1979. In parallel with the international effort, Canada established the Canadian Climate Program in that year, to improve understanding of the implications of global climate change predictions to the country and to Canadians. Since then, the number of Canadian scientists working on climate change issues has grown, first for the atmosphere and oceans, and more recently for terrestrial and marine ecosystems. Several Canadians, including DFO scientists, played an important role in preparing the first report (1990) of the Intergovernmental Panel on Climate Change. Supported by the national and international scientific communities, Canada then signed the international Framework Convention on Climate Change in 1992. In 1997, Canada signed the Kyoto Protocol, committing Canadians to address climate change through a variety of domestic actions, ranging from improving knowledge on climate science and the impacts of climate change, to implementing mitigation and adaptation programs.

The identified effects of climate change on Canada's environment have become more numerous since 1979, more widespread in scope, and less speculative. DFO scientists participated in the Canada Country Study (CCS), published in 1997, which postulated effects ranging from changes to ice and permafrost regimes in the Arctic, to sea-level changes on the Atlantic coast, to reductions in southern stocks of Pacific salmon. The CCS suggested increased emphasis on ecosystem effects, and on human communities, through studying the sensitivities of living systems to the changes foreseen in the physical environment.

The Ocean Climate initiative, included as part of DFO's response to the Green Plan, brought increased research funding for six years beginning in 1991/92. Science Branch funding was used mainly for two areas: improvements to ocean modelling and the underlying data, and improvements to the knowledge of primary production and carbon cycling. The latter program, part of the international Joint Global Ocean Flux Study (JGOFS), included work on the response of primary production to new carbon inputs, the transfer of carbon off the continental shelf, and its sequestering in sediment.

With the end of the Green Plan, an Ocean Climate Program (OCP) envelope was established in DFO Science Branch in 1997/98, in recognition of the need for a dedicated climate science program, and it is this program that remains in place today. The OCP and other priority funding initiatives have created a network of projects in three oceans, including those that address climatic influences on fish. These and other OCP projects contribute to the Department's Climate Impacts and Adaptation (CIA) science activities.

The Canadian Climate Action Fund (CCAF) was established in the government's budget for 1998-99, to accelerate programs in four areas. A Foundation envelope was set up to promote policy and strategies related to Canada's obligations under the Kyoto protocol. An envelope for Science, Impacts, and Adaptation was set up to promote understanding of the processes involved in climate change, and the effects of those changes on Canadian ecosystems and society. A third envelope was set up to address Technology Early Action Measures, thus making progress towards the emissions targets set at Kyoto. Finally, a Public Outreach envelope was established to transfer information and knowledge, and to help move the dialogue on climate change more to the forefront of public issues. DFO scientists have received CCAF funding from the Science, Impacts, and Adaptation envelope, with submissions for the final year of this program being presently under review.

DFO held a national workshop in November 1999 to review the OCP and to establish strategic directions and priorities for climate change science generally. As a follow-up to this workshop, and as part of an ongoing review of scientific programs, DFO has requested this brief inventory of Climate Impacts and Adaptation Science activities presently underway in the Department. This report compiles the activities underway and the needs identified by departmental scientists and managers and by informed people outside DFO. The primary tool used in assembling the information in this report was telephone interviews with regional and headquarters staff. Additional interviews were completed with staff from Environment Canada, Natural Resource Canada, and universities (Table 1).

Scope of the Review

Impacts science encompasses research whose main purpose is to anticipate the vulnerability of a sector to climate change. (Major sectors are listed below.)

The elements of vulnerability are an effect (including its nature, direction, and magnitude) and susceptibility (i.e., the sensitivity of the sector to a changed environment). Thus Impacts science is oriented to if and how a sector and the resources it depends on might change. Research whose main purpose is to understand, monitor, and predict processes that would cause sector changes does not fall within the scope of this project.

For DFO, the major sectors are:

- the fisheries sector, including aquaculture
- marine transportation
- the offshore industry, including minerals, oil and gas
- traditional culture that depends on marine wildlife
- coastal zone management concerns (e.g., erosion and storm surges, fishing community issues).

Adaptation science encompasses research or data and information products whose main purpose is to help a sector adjust to climate change, so that it continues to be sustainable in the face of the new environmental conditions.

DFO must acquire and manage ecosystem monitoring data to help validate predictions and to document the evolving effects of ocean climate change. Ecosystem monitoring science is being examined by the LMR-GOOS task (Living Marine Resources task, Global Ocean Observing System) and so is excluded from this compilation. It is well recognised, however, that ecosystem monitoring research and data are the foundation for knowledge about impacts and adaptation. LMR-GOOS is developing international understanding of what is and what should be monitored. Monitoring data needs to be stored and available. Availability continues to be an issue because data management procedures are inappropriate to general access requirements. DFO scientists need access to the whole spectrum of monitoring data to develop impact hypotheses and predictions. If monitoring and data management processes are put in place for the longer term, the tools and predictions developed through an Impacts science program can feed back into monitoring needs.

DFO will have to be innovative if it is to build the non-resource species data that are needed to manage from an ecosystem perspective. First steps have been taken with the establishment of a national program of improving the information available for primary and secondary production. An efficient approach elsewhere would be to build on existing programs, as is presently being done on the East coast, to ensure that data collection needs are integrated with other programs. With oceanographic and biological research activities generally taking place in separate divisions, opportunities to collect complementary data are often missed because the complementary skills and equipment are not available to scientific and technical staff. Small resource increments, especially at the level of technical staff and equipment, would help Science Branch to obtain complementary oceanographic or biological information from field programs.

Progress in CIA science will also require linkages with modelling efforts. Scientists and managers interviewed for this project often had suggestions about these linkages and for the kinds of model output that would be useful. These ideas were forwarded to a companion project on modelling needs, presently being undertaken for DFO by 2WE Associates.

General Considerations

Work Underway

The Climate Impacts and Adaptation (CIA) work underway in the Science Branch of DFO is a blend of projects with local, national, and international roots. Locally developed projects have generally arisen out of interest in a particular species or ecosystem, and the level of effort in these projects is often difficult to assess. Many scientists interviewed to obtain the information for this report said that their CIA activities were a small but important part of their other project responsibilities. Such work tends to be an offshoot of stock assessment science, with examination of climate variability being used, perhaps on the one-to-two year time horizon consistent with stock forecasts, to help explain recruitment and distribution patterns.

The major regional science bodies for the North Atlantic and North Pacific are the International Council for the Exploration of the Sea (ICES) and the North Pacific Marine Sciences Organization (PICES), respectively. Although both have other working groups involved with aspects of climate change, the Global Ecosystem Study (GLOBEC) is probably more influential in terms of providing an international framework for some of the Department's CIA activities. GLOBEC's Canadian program involves scientists from seven universities with DFO's major East and West coast labs in a program to look at the causes of interannual-to-decadal fluctuations in marine ecosystems. A coordinated four-year program of field and modelling studies has been undertaken with funding from the Department and NSERC. Results from the first four years of study are beginning to appear in the *Canadian Journal of Fisheries and Aquatic Sciences*, and a special issue is planned for March 2001.

GLOBEC projects represent a significant investment by the Department. Priority operational funding of $350-$400K annually has leveraged at least another $1,000K annually for vessel and staff support. In addition, NSERC has funded the university side of the program at about $1,000K annually, of which about $250K comes back to the Department in the form of PDFs working mainly at DFO labs. GLOBEC is presently in its last year of funding, and DFO has participated in proposals for its renewal.

A sub-working group of the 5NR Departments Working Group on Climate Change Variability is just beginning its activities. Called the Ecosystem Impacts and Climate Atmospheric Change Sub-working Group, this initiative is an attempt to provide managers with ongoing advice about the effects of climate change.

Needs

While almost everyone interviewed in this study had one or more ideas for new CIA activities, several recent and more comprehensive sources of information exist. The most readily available are:

- the Options Paper for Science, Impacts and Adaptation (November 25, 1999) prepared by the Canadian Climate Program Board (CCPB)
- DFO's draft position paper on Climate Change Science and Impact Research (May 1998)
- the draft Ocean Climate Strategy for Canada, developed by DFO on the basis of a workshop in November 1999
- the Canada Country Study (1997), referred to above.

Recommendations from these documents on the future of CIA studies are summarised below. They offer wise advice for the future. A common theme is that we do not need to wait for the results of coupled ocean-atmosphere models at regional scales in order to start CIA activities. In general, these recommendations are reflected in the climate science activities underway in DFO, especially in Impacts science. Adaptation science in DFO is less developed, however. DFO's implementation of general recommendations about translating the results of Impacts analyses into economic analyses and then work with industrial and community sectors, seems to be almost non-existent.

CCPB Options Paper

- Investigate impacts and vulnerabilities related to historical and current climate patterns.
- Define thresholds, sensitivities, and vulnerability for key species, and for ecosystems and social/ economic systems.
- Start detailed case studies in each region of the country to explore the impacts of climate change and the ways of reducing society's vulnerability.
- Focus limited resources on key sectors and regions of the country that are already experiencing significant impacts and are at the greatest risk of change.
- Develop partnerships; invest in developing new researchers; coordinate, facilitate, and manage across jurisdictions.

Draft DFO Position Paper

- Investigate the vulnerability of the freshwater phases of salmon.
- Learn more about the effects of trends in salinity, temperature, and the hydrological cycle on primary and secondary production.
- Study species at the geographic limits of their range to learn about limiting factors.
- Improve knowledge of basic biology for keystone species, especially for areas like the Arctic where the lack of basic understanding is a barrier to Impacts science.

- Develop calibrated ecosystem models.

Draft DFO Ocean Climate Strategy

- Continue research into primary and secondary production and their relationship to physical and chemical parameters.
- Study special places important to living organisms and where changes to physical conditions will have important effects.
- Invest in new researchers and rebuild the capacity for critical field studies.

Canada Country Study (CCS)

The Canada Country Study's conclusions and recommendations were developed in regional, sectoral, and cross-sectoral formats, with the sectoral considerations including fish and wildlife. Recommendations from the CCS sectoral and cross-sectoral chapters relevant to DFO would be an excellent starting point for future DFO programs. These recommendations are summarised here for quick reference, but are best read in their original form.

Impacts Science

- Develop climate change scenarios based on case studies of recent extreme events (e.g., El Niño) and assume that reductions in the return periods of these events are likely.
- Conduct research to link available biological/ecological information on the impacts of climate change to local resource use and the northern economy.
- Determine the effects of non-linear, sudden changes in climate in northern regions.
- Determine the limits to adaptability in northern subsistence economies.
- Enhance monitoring activities and develop compatible and accessible databases across Canada in the areas of structure and functioning of marine and freshwater aquatic ecosystems and their component species (commercial and non-commercial); socioeconomic parameters (e.g., fisheries statistics); ocean climate; and extreme events.
- Conduct long-term multi-disciplinary research on fundamental ecological (i.e., physical and biological) conditions, sensitivities, and trends.
- Develop ways of using traditional ecological knowledge to complement scientific knowledge.
- Conduct studies in regions lacking attention: the eastern Arctic, northern Ontario, and Labrador.
- Improve knowledge of the life history of fish and other marine organisms.
- Conduct comparative studies of aquatic ecosystems and fish populations across latitudinal gradients.
- Increase understanding of factors determining fish distributional patterns.
- Improve knowledge of the life history of salmonids.
- Monitor biological responses and ecological climate indicators in representative aquatic ecosystems with significant fisheries.
- Improve understanding of linkages between climate and variations in marine productivity.
- Improve basic knowledge of Arctic marine and freshwater biota life histories and productivity levels.
- Assess impacts of sea-level rise and river discharge declines in estuaries.

- Improve estimates of ecosystem and fishery carrying capacities.
- Improve measurements and valuations of subsistence and native fisheries.

Adaptation Science

- Assess how Canadians perceive their risks related to natural hazards and climate change, to improve understanding of the context for adaptive decisions.
- Improve projections of the impacts of climate change on physical and biological processes, and on socioeconomic sectors.
- Convert such physical and biological changes into socioeconomic values (costs and benefits) to further inform adaptation strategies.
- Improve or develop estimates of the costs over time of adaptation to, and residual impacts from, climate change
- Include consideration of competing interests (e.g., the fishery), current policies, and boundary demands.
- Conduct research on the implications of climate change for the international fisheries sector, including the implications for Canada.
- Conduct research to develop adaptive management strategies for the North, with emphasis on the resilience of social and ecological systems, and on flexibility to respond to uncertainty.

Consistent with views expressed at DFO's recent workshop (November 24-26, 1999), the emphasis on regional needs in the CCS cross-sector chapter is on the Arctic, where observations indicate that the climate is warming, and for which models suggest that effects in the physical environment will be felt to a greater degree than in the south, especially in winter.

As is the case with the CCS sectoral and cross-sectoral chapters, the CCS regional chapters contain more detailed summaries of impacts and needs than are to be found in the CCPB Options Paper or the two recent DFO drafts. The material relevant to CIA activities in DFO is summarised at the start of each regional section below, and again offers directions for future programs.

Pacific Region

Summary from the CCS

The possible impacts of climate change on the natural environment of the BC and Yukon Region provide the physical setting against which to view CIA activities in DFO.

- Sea level will rise by up to 30 centimetres on the north coast of British Columbia and up to 50 centimetres on the north Yukon coast in the next 50 years (implications for wetlands, infrastructure). The rise in sea level on the south coast will be less. On the other hand, isostatic rebound of the earth's crust from the effects of the last glaciation may partially offset these effects, depending on the coastal location (e.g., Vancouver Island appears to be twisting, sinking on the central west coast and rising in the southeast.
- Spring flood damage could be more severe and frequent along rivers and streams of the coast and throughout the interior of British Columbia and Yukon (implications for salmon habitat).

- Stream flow in late summer and fall will likely decrease along the south coast and the southern interior, while stream temperatures will rise (implications for pre-spawning mortality).
- Landslides and debris torrents in unstable mountainous areas of British Columbia and Yukon will become more common as winter precipitation rises, permafrost degrades, and glaciers retreat (implications for salmon passage and fish habitat).
- Many glaciers in southeastern British Columbia and the southern Rocky Mountains could substantially melt or disappear completely (implications for hydrology, salmon habitat, coastal productivity).
- Increased sedimentation, coastal flooding, and permanent inundation of natural ecosystems will occur in low-gradient, intertidal areas (implications for wetland productivity).

Contributors to the CCS believed that these impacts could affect fisheries and marine life in several ways, and could affect aboriginal peoples.

- Important salmon stocks from the Fraser and other southern rivers may decline. In northern BC rivers, salmon productivity may increase.
- Pacific cod abundance likely will be reduced.
- Exotic species will be introduced from the south. Cold water fish, such as trout, char, whitefish, and grayling, may suffer as water temperatures rise.
- Changes in the distribution and abundance of key fish and wildlife resources will negatively impact aboriginal lifestyles.
- The spring floods will wash increased amounts of organic material into estuarine areas, resulting in fish kills due to oxygen depletion.

The Regional Perspective: Work Underway

Pacific Region is planning a regional workshop on CIA science and data needs, to be held sometime in March 2000. The agenda was being developed at the time this report was being written.

Information obtained from the interviews indicates that the level of effort in Pacific Region on identifiable Impacts science projects is in the range of $600K annually. No one interviewed for this report indicated that any Adaptation science was underway in the Pacific and Yukon Region. No specific Adaptation work was called for in the CCS, other than the implied need for studies into ways in which First Nations might adapt. It might be noted, however, that First Nations coped with cycles in abundance and distribution of plants and animals for several thousand years, and that the variety of plants and animals they harvested reflected what was abundant.

On the Impacts side, a project is underway to determine changes in the marine growth patterns of BC salmon stocks, and to relate growth to offshore patterns of ocean warming, variations in zooplankton biomass, and salmon abundance.

Observations are being made of the annual cycle in C:chlorophyll and N:chlorophyll ratios in the subarctic Pacific. These observations are being used to improve conversions between observations of phytoplankton chlorophyll, carbon, and nitrogen in models of the planktonic ecosystem. A submodel is being developed to estimate seasonal variation in the ratios.

Work is underway to develop a series of increasingly detailed planktonic foodweb models, all initially embedded in a simple one-dimensional mixed-layer model. In the subarctic Pacific, a total carbon submodel will also be formulated. The overall objective is to be able to hindcast past changes in productivity linked to climate changes, and to make projections into the future.

A simple box model of the North Pacific subarctic and subtropical gyres is being coupled to an energy-balance box model of the atmosphere, and used as the physical environment for a model of the embedded biological systems. Associated nutrient and iron budgets, coupled with rudimentary species differentiation at the phytoplankton level, will permit evolution of both biomass and species composition of the biological system as the physical environment changes. This model will be used to determine the level and mechanisms of the "natural" variability in ocean primary productivity, which in turn affects oceanic fish stocks and CO_2 uptake. The model will serve as a "toolbox" for:

- determining sensitivity of ocean ecosystems to poorly known parameters
- understanding the mechanisms at work in coupled ocean-atmosphere general circulation models
- extrapolating results of CGCMs to the longer time scales associated with anthropogenic climate change.

A multi-year study is underway to determine how the changes in general atmospheric circulation and decadal-scale changes in Earth rotation relate to the dynamics of salmon, groundfish, herring, halibut, and sablefish. The study includes an examination of the influence of oceanic and freshwater regimes on the abundance, behaviour, and distribution of salmon.

Work is underway to determine the predictability of high-water effects on coastal erosion and flooding. Areas vulnerable to flooding and erosion, such as beaches and First Nations reserves, are being identified, with a focus on the Vancouver area. Much of the BC coast is not vulnerable because of the steep shoreline topography. The project is looking at the effects of water levels during El Niño events, which can bring sea level up by an average 30 centimetres for the duration of the winter. The objective is to investigate whether predictions can be made well enough to issue flooding and erosion warnings. The project is being done in partnership with Environment Canada.

One benefit of developing and applying ecosystem models is thought to lie in the insight and improved accuracy to be gained from an approach that determines population levels on the basis of more than fishing mortality. A static mass balance model (called Ecopath) developed at UBC, starts with the process of primary production and follows the flow of energy upwards through the food chain. In Pacific Region, recent data on climate variability and the strength of fish stocks are being used to develop impact scenarios. Once relationships have been set up, the next phase of work will be to use another UBC model, called Ecosim, with climate instead of fishery as the forcing term. For each of the major species, an ecosystem management chart has been developed that considers the effect that a decrease in that species would have on other species. The output of the model would be forecasts of impact, which managers could use to consider adaptation. Ecosim has six or seven components, each of which would take perhaps two years to complete.

In light of the destruction of kelp beds in Washington State during the last El Niño, a project is underway to look at the impacts of El Niño events on kelp communities. Kelp communities are very productive components of the coastal ecosystem and provide important fish habitat. Studies of relationships within the kelp have the potential to reveal the vulnerabilities of these communities, in addition to providing information useful for harvest management.

A thermal and hydrodynamic model of Fraser River salmon habitat, called IFSAM, has been in use as an in-season management tool for several years. The model forecasts pre-spawning mortality due to high temperature and river flow conditions. A new project is underway to enhance the model so that it can be used to examine the sensitivity of Fraser River sockeye salmon to climate change.

Some CIA work is being done on invertebrates, for example, in shrimp stocks where there is a large environmental component to stock signals. The invertebrate stock assessment group is looking at the relationship between shrimp populations and oceanographic factors during El Niño periods. This work is not a discrete project but is being undertaken as part of the stock assessment process.

One limitation of the stock assessment cycle from the perspective of CIA science is its annual or biannual focus. Some work is underway for pelagic fish to put stock assessment data into the broader context of climate change. Work is also underway to look at shifts in species composition, especially in planktonic communities, relating them to possible climate forcing signals. This work could have implications to the fishery, in establishing whether controls over ecosystem productivity are top-down (i.e., driven by predation) or bottom-up (i.e., driven by production). This work is part of GLOBEC.

The Pacific Stock Assessment and Review Committee (PSARC) has established a fisheries oceanography working group, which plans to publish a state of the ocean report for 1999, reviewing physical conditions and general biological trends.

Regional Perception of Needs

Information about the ways in which climate change will affect the Georgia Basin is probably better than the information about animals that live in it. Potential shifts in productivity need to be further explored.

Storms will be more intense, implying that coastal structures need to be better guarded. A warning system is needed to help those responsible for coastal infrastructure.

The IFSAM model should be coupled to the modelling efforts underway for the relationships between climate variables and salmon at sea. It is not clear how this might take place, especially with the duties and preoccupations of existing staff, but the benefits of having a life-cycle model for salmon habitat seem evident.

The international GLOBEC program emphasises linking ecosystem models to social response. Shifts of the fishery from low abundance to higher abundance species take place all the time, but a study of the limits to this type of adaptation in BC should be carried out.

The response of salmon to thermal changes in the North Pacific continues to be a priority for research funds. The projections made for a shrinking habitat need to be coupled with an improved understanding of why salmon seem to follow thermal limits while at sea, how fish production overall in the North Pacific might change if the oceanic ranges for salmon species indeed shrink, and what other species might benefit. This work would involve multi-species investigations of habitat requirements and the factors determining distributional patterns.

Central and Arctic

Summary from the CCS

The impacts identified by the authors of the CCS have serious implications to northern fish, wildlife, and the communities that depend on them.

- The effect of rising lake temperatures on fish habitats in freshwater is uncertain. Many species in lakes and streams are likely to shift poleward by about 150 km for every 1°C increase in air temperature, with 5-7°C winter increases being forecast.
- Some species (e.g., the sea otter and warmer water fish) could move into new territories.
- Sustainable harvests for most marine and freshwater fish populations may increase.
- The distribution and characteristics of polynyas and the ice edges that are vital to Arctic marine ecosystems will change.
- The range and numbers of some Arctic marine mammals, such as beluga and bowhead whales, may increase or at worst hold steady. Ringed and bearded seals, sea lions, and walruses may suffer declines brought on by pack ice recession.
- The longer ice-free season could entail greater wave heights, coastal erosion, and flooding of coastal infrastructure.
- Climate change could alter many aspects of life in Arctic communities, adding onto the many other forms of stress faced by aboriginal people.
- The impacts on Arctic marine shipping would likely be significant.
- Altered design criteria are to be expected for the offshore oil and gas sector, but the sector historically has been very adaptive to environmental conditions

The projected effects on marine shipping have implications for the conduct of Science activities. CCG reports that the marine weather is becoming more variable and storms are more severe. The storms form ice ridges and move ice sheets, making navigation more difficult. On the other hand, there is no question that the navigation season in the Arctic is getting somewhat longer. A change in the seasonal ice regime will alter capabilities to work from ships and the ice.

The CCS chapter for the Arctic discussed research needs at a general level.

- Knowledge of the eastern Arctic is generally poorer than for other Arctic regions. This lack of basic understanding hampers efforts to build relationships between climate variables and the biophysical environment.

- Relationships between climate and socioeconomic sectors in the Arctic are even more poorly understood than those between climate and the biophysical environment.
- There is a pressing need for real partnerships between researchers and users in both developing and carrying out impact-related research for the Arctic.
- Traditional ecological knowledge should be more effectively utilized, particularly in respect to quantifying terrestrial and aquatic environmental sensitivity to climate.

The Regional Perspective: Work Underway

Few identifiable Impacts science projects are underway. The Central and Arctic Region has arranged a workshop on climate change impacts and adaptation strategies in Canada's northern regions in cooperation with Environment Canada and NRCan. The program includes sessions on assessing climate change impacts and the options for adaptation, and the identification of research and data needs to support adaptation strategies. The workshop will take place on February 27-29, 2000, in Yellowknife.

Work is underway at the population level on seals, whose numbers are intimately linked to ice conditions and to predation by bears. Ringed seals may serve as a useful indicator of climate change effects, and work is proposed (CCAF) to look at their population ecology at the southern edge of their range, in Labrador and James Bay.

The Ocean Climate Program funded a three-year project on Arctic char, now in its last year. Char populations at each end of the latitudinal range are lacustrine, rather than anadromous. If the southern populations went to sea, the temperatures there would be above optimum, while marine opportunities are restricted at the northern extreme. The project looked at latitudinal variation as a proxy to anticipate what the potential effects of warming might be. Biological variables were linked to climate indicators to show the effect of different conditions on char productivity.

Adaptation to climate change in the north have to be considered in the context of the enormous changes that are still taking place in traditional lifestyles. While northerners seem ready to discuss the terrestrial impacts of a warming climate, DFO's experience at Board meetings and with land claims groups indicates that these groups are less ready to think about the marine effects. Traditional hunters believe they can cope with species shifts, as they always have, with their concerns being whether the animals will come or not, when they will come, and where they will be available.

There is a need to work with northern communities to help them adapt, and to explain to communities what climate change will mean to them. Enough is known about marine impacts (e.g., time of breakup and extent of ice cover) to begin discussions about the implications for traditional life. Adaptation discussions will, however, be more relevant when they focus on biological effects, rather than on the physical impacts. Issues related to access to hunting grounds also need discussion.

Adaptation in the fishery will mostly be limited to reducing exploitation or shifting the targets, and fisheries managers may be better equipped than many scientists to undertake discussions at the community and Board level. They will, however, require timely and ongoing information from Science Branch on the likely Impact and Adaptation scenarios. Not much Adaptation science is underway in the Region, primarily because the details of impacts are insufficiently known.

Regional Perception of Needs

Understanding of how inter-annual and decadal-scale cycles interact with each other is especially important in the North. The issue of whether the changes being seen are part of cycles, and if the changes will be persistent, still awaits resolution. Given the shortness of the historical record, both proxy methods (tree rings, etc.) and traditional knowledge could be used to indicate whether similar changes have taken place in the past. Some combination of scientific and anthropological investigation seems needed.

Knowledge of walrus, beluga, and narwhal relationships to ice and open water conditions is not good enough to develop sensible hypotheses of the effects of a general warming in northern waters, and there are gaps in the knowledge of narwhal distribution in summer. Major questions surround the availability of food in a general warming scenario, in particular, changes to the status of Arctic cod and macro-benthos. There are also gaps in the sex and age data for some exploited populations, because effort is presently concentrated on the small, vulnerable stocks.

Impact hypotheses in the North are hampered in many cases by the poor understanding of basic biology. The thermal niche requirements for many northern species are unknown. Also, for anadromous populations of char, the hydrological implications of changes in the amount and timing of runoff events should be investigated. There is no project underway in freshwater to monitor species shifts towards the north, although some information is being gathered on the occurrence of southern species in the Beaufort Sea. Knowledge of marine fish biology, species distributions, and life history requirements are not known well enough to develop impact hypotheses. For example, some Arctic cod populations seem to require ice niches for a part of their life, but the reason is unknown. This means that the consequences for Arctic cod of the ice disappearing can only be guessed.

A fishery for turbot in Cumberland Sound has been underway for about 10 years. This long-line fishery is prosecuted from the ice surface, and so is vulnerable to changes in ice thickness and distribution. Historical satellite imagery for the area might be assessed in conjunction with information about fishery landings and the location of the fishery.

The Canadian Hydrographic Service has an important role to play in CIA science, especially in the north, but more generally where there are concerns about the effects of sea-level rise on coastal infrastructure and shoreline erosion. While seasonal water-level gauges are put into the Arctic each year, the only permanent gauge is at Churchill. Sea level in the Arctic tide tables has not been changed since the 1960s, despite knowledge about isostatic rebound on the Arctic coast and evidence from Churchill that the water level is falling at about 1 metre per century. Isostatic rebound in the Arctic might thus offset the sea-level increase projected from climate change, reducing the potential for damage to infrastructure and the erosion of the coastline that would otherwise occur. While this may be seen as an interdepartmental issue, DFO is not well-positioned to offer scientific information and data.

Sea-level rise is an important consideration in the Arctic. If the open-water season lasts longer in the fall, seasonal storms from the north will interact with sea-level rise to accelerate coastal erosion. There seems to be a need for a few more permanent water-level gauges. Once data became available, they could be coupled with a model that assimilates satellite altimetry data to interpolate between the points. Such a model might also be adaptable to other regions of the country to help offset the effects of degradation of the permanent water-level network.

There may also be a partnership opportunity with NRCan to map the present coastline at high and low tides from remote sensing imagery during the open-water season. The maps produced could be compared with historical data, and used to track coastal changes and to inform predictions for vulnerable areas.

Laurentian Region

Summary from the CCS

The CCS chapter on Quebec and the Laurentian Region is especially detailed in the area of research needs. The doubled CO_2 scenario for Quebec indicates seasonal warming that is most pronounced in winter: up to 6°C in the south and up to 9°C in the North. The south will show a drying trend, while precipitation in the north will increase. In the south, there is a risk that wetlands will dry out, reducing production. Little Adaptation science has been done.

- Only qualitative evaluations of the potential impacts of climate change on ecosystems and wetlands are available. Knowledge is better for freshwater than marine ecosystems, and better for the south than the north of Quebec.
- The factors responsible for natural variability in fish and marine mammal populations need to be better understood. The critical stages in the development of species should be identified and the physical and biological factors influencing the survival, growth, and fecundity of individuals should be determined.
- Studies should be undertaken on redfish and other species to determine their sensitivity to seasonal changes in temperature and wind-induced upwelling.
- Focussed work is needed, mainly on the St. Lawrence River, on the relationship between variations in water levels and use patterns, riparian ecosystems, and the different life stages of aquatic fauna.
- Studies are needed to improve understanding of ecosystems in the St Lawrence basin and their interaction with the present climate and paleoclimate.
- The thermal and hydrological tolerances of species at the edge of their geographic range should be investigated, especially in ecosystems at risk (e.g., wetlands).
- Studies should be conducted on the effect of an increase in CO_2 on the growth of plant species (riparian and aquatic).
- CIA studies in the St. Lawrence basin are important, because the effects of climate change may have a bearing on the management of water levels in Lake Ontario and downstream.
- There are strong concerns about the effects of low water levels on ports and marine transportation.

The Regional Perspective: Work Underway

Work is just getting underway on the relationship between habitat production and ecosystem changes. A scientist has been hired to work on issues related to benthic productivity, and later this year a scientist will be hired to begin developing ecosystem equations, perhaps using the Ecopath model. Similar exercises are underway in the other major labs on the East coast, with benefits for inter-regional coordination and the use of resources.

Work on the models needed by Impacts studies is underway. Regional models are being developed for the Gulf of St. Laurence and Hudson Bay, with boundary conditions taken from the Canadian GCM. Because the Gulf of St. Lawrence is a semi-enclosed system, the boundary conditions are more straightforward than for many places, making the Gulf a good experimental laboratory. The cold intermediate layer in the Gulf determines the distribution of many fisheries resources, such as crabs, shrimp, lobster, cod, and capelin, and scientists would like to look at the impact of these changes on fish resources.

Regional Perception of Needs

The existing work in DFO and at universities seems to be directed mostly towards improving predictions of physical effect. The use of model outputs to develop impact hypotheses is less developed. Some of the needs for the Gulf are outlined in the CCS. Changes to the runoff regime for the St. Lawrence and its major tributaries will have important effects on wetland and riparian habitat that require clarification. The possible changes in temperature and salinity are not well defined, but primary and secondary production, fish distribution, and growth may all be affected. The St. Lawrence is a useful laboratory for trying out ecosystem models, and work in this area is only just getting underway.

The northeast part of the region is less well-studied than the Gulf of St. Lawrence. The implications to the marine resources of Hudson Bay of the significant warming seen for northern Quebec should be evaluated. Problems similar to those elsewhere in the Arctic will be encountered, however. Little is known about environmental or seasonal influences on biological factors, such as growth and distribution, and more basic work will need to be done.

Maritimes

Summary from the CCS

The CCS chapter for Atlantic Canada covers both the Maritimes and Newfoundland regions. Highlights are summarised below.

- The distribution and migratory patterns of fish species will change, as will growth rates and recruitment success, and changes in the ratio of deep sea to groundfish abundance.
- The life cycle of many species will be affected by changes in timing and magnitude of freeze-up and break-up, the severity of the spring freshet, and the duration of the low-flow periods.
- Knowledge of the life history of species needs improvement.
- Ecological models will require a better understanding of the role played by the environment, species interaction, and fishing in determining the variability of growth, reproduction, distribution, and abundance of fish stocks.

- Relatively little is known about the northernmost two-thirds of the region, which is the area most likely to be affected.
- Storm surges and coastal erosion will affect wetlands. Coastal ecosystems processes affected by storms, erosion, water level changes, and sedimentation should be investigated.
- A decrease in river ice would be detrimental to some aquatic species.
- Coastal sedimentation processes will be altered and sediment distribution patterns will change.

The Regional Perspective: Work Underway

Work has been done under the Atlantic Coastal Action Plan (ACAP) to help communities map areas that will be flooded by higher water levels. Mapping for vulnerable areas (e.g., areas around Wolfville and the head of Minas Basin) is showing what would be flooded at different storm surge heights. This is one of the very few identifiable Adaptation science projects underway in the Department.

Another Adaptation project is underway to map flood risk from storm surges in four areas, using airborne laser to develop detailed topography. This project is in part a feasibility exercise to show stakeholders (municipal, provincial, insurance industry) how it can be done. While there is considerable interest from some stakeholders (e.g., the insurance industry and the Provinces), it is apparent that nobody wants to underwrite the total cost of an expanded program.

As on the West coast, research is underway to relate stock assessment time series and changes in abundance to environmental time series. Forecasting the influence of climate change on haddock and cod will require a synthesis of environmental monitoring data at appropriate scales. The appropriate scale for modelling output varies from place to place, but on George's Bank this scale is about 2 degrees longitude. Bottom temperature data are obtained in conjunction with groundfish trawl surveys, which are done only at two times of the year.

An experimental storm surge model, run by EC, needs ongoing access to water level data more accurate than is presently available. Work is being undertaken to build a three-dimensional (time, height, geographic extent) representation of mean sea level for the entire East coast of Canada, using data from the water-level network and an ellipsoid model to interpolate between sites with adequate data. A more detailed model is being built for the southeast Gulf of St. Lawrence to show the departure of mean sea level from chart datum.

Work is underway to investigate changes in the ecology of the eastern Scotian shelf, which has become colder and fresher, with capelin and Arctic cod moving southwards. Spatial changes in groundfish (cod, haddock) distribution are being characterised at local scales on George's Bank. This project, a part of GLOBEC, may still be underway when GLOBEC funding ceases at the end of March 2000.

Regional work on the impacts of climate change on northern cod stocks is also being undertaken in support of GLOBEC. An ICES working group on cod and climate has, for the last decade, undertaken a retrospective analysis of events in the North Atlantic. This work is helping to isolate the influence of environmental factors on cod growth across the North Atlantic, to determine the extent to which these factors can be separated from fishing and other density-dependent factors.

Work is underway on the Labrador shelf and off Newfoundland to relate recent cold water conditions to effects on cod, snow crab, haddock, and capelin. Statistical models are being developed to relate temperature to growth, recruitment, and survival. The role of currents in transporting lobster larvae to the coast is also being examined by seeding physical circulation models with particles that represent larvae dispersing from spawning areas. The larval distribution model will eventually be used in conjunction with forecast variability in temperature, wind field, stratification, etc., to look at climate impacts.

The Ecopath model is being used in Maritimes Region, as well as in Pacific and Laurentian Regions. Existing knowledge is being synthesised to build the equations for different areas and different time periods, beginning with the early 1980s. Further work on the equations for primary and secondary production would improve the model, as would more data on absolute abundance of the most important prey species. The link to climate is currently speculative, because of uncertainty over how to mediate the changes.

A conventional process dynamic model is also being developed. Work is presently at the level of three species, with feedback benefits being reported for comparisons between the two models.

Regional Perception of Needs

DFO prepared a review in 1988 on the effects of climate variability on fish, based on model output available at the time. This work developed scenarios about changes in the Atlantic fishery that might occur as the ocean responded to CO_2 increases. While a decline in northern cod stocks was projected on the basis of salinity changes, other forecasts included a decline in overall fisheries production related to a shift in phytoplankton species composition towards dinoflagellates, brought on by increased stratification. This hypothesis could now be tested using data from the Plymouth (UK) ship-of-opportunity program.

The Maritimes and Laurentian Regions developed a joint proposal to systematically review the changes predicted in 1988, to see if any of them could be verified. The proposal was not funded in the last cycle of the CCAF, and the verification remains an important need.

Much basic biology remains to be done to link climate variability to fish growth, survival, etc. Biological models often do not have enough information to develop good equations and, as in other regions, stock assessment responsibilities claim the major portion of biological effort.

In order to use outputs from regional modelling, we need to have the information about sensitivities. There is a chance that working on the basic biology will not uncover the linkages useful for modelling. Retrospective analysis using statistical and numerical models may provide hints, and the basic biological work should be addressed along these lines.

There is concern about how the trend towards warmer, drier summers will affect salmon rivers. The consequences to salmon smolt runs might be investigated using historical data on extremes.

Ecosystem impact projections would benefit from access to an index of environmental information (e.g., a temperature index), which can be used as a proxy for some of the effects of climate change.

Changes to the salinity of the Bras d'Or lakes may impact Cape Breton's oyster culture industry. Studies should be undertaken, perhaps in partnership with the industry, to evaluate the risk that areas of the lakes will become unsuitable.

Sea-level changes in the Bay of Fundy and storm surges are a concern. While some work has been done with stakeholders, primarily in the area of flood mapping and flood risks, most Maritimers do not have much understanding of the coastal and marine effects of climate change. There is a need to get coastal communities more involved in anticipating the adaptation that have been inferred from GCM predictions.

Statistics on the frequency and size of storm surges would be useful on all three coasts as a baseline for future comparison. These statistics can also be used to develop risk estimates for extreme events (e.g., a 100-year high-water level), which is a topic of interest to the insurance industry.

A stand-alone harmonic tidal model is needed for the East coast, from Cape Chidley to the US border. Its construction would take about three years and $300K. Besides providing assistance for hydrographic surveys, such a model would have a variety of other uses, including for SAR and oil spill prediction.

Newfoundland

The CCS chapter for Atlantic Canada covers both the Newfoundland and Maritimes regions. Highlights are summarised in the "Maritimes" section, above.

As in other regions, much of the CIA work in fisheries science takes place around the edges of stock assessment. Interviews did not uncover any formal CIA science projects in the Region. Scientists are, however, looking at changes in ocean conditions and trying to relate them to population changes. The relationships between environmental variables and several species or stocks has been documented in several recent papers, including work on capelin, cod, salmon, and flatfish.

The ICES thermal habitat model is being used to forecast salmon returns in Labrador, but the level of effort involved is low. Because the Province closes recreational fishing when stream temperatures rise, the implications of warming to the recreational fishing sector are a concern. Effort should be put into work to better delineate impacts in this area and to work with the industry.

The Region has a capable oceanographic group, although a small one, and would like to do ecosystem modelling at the base of the food chain (e.g., using a model like Ecopath) to take advantage of the information available from monitoring data. This cannot be done without new staff.

Cross-Regional Needs

Several scientists and managers interviewed expressed a wish to see the area of climate change impacts explicitly recognised as a priority for Science Branch. The most tangible expression of management interest comes in the form of funding and headquarters support, and it is to be hoped that the present 5NR initiative to secure continued funding will benefit DFO in both these areas.

The most important need is for scientists to identify and be clear about what is known. The next most important need is to communicate this amongst the scientific community and to the public.

Decision makers will require information about impacts and adaptation on a more or less continuous basis to manage and conserve the resources that are part of the Department's mandate. To achieve this will require shifts in science funding to meet today's needs. As a prelude to investment in local-scale research, it might be beneficial to undertake a national assessment for southern Canada, based on existing data. Such an activity would advance modelling capabilities in the Department, would extract additional value from existing data, would refine understanding of critical data gaps, and would place the Department in a better position to undertake Adaptation projects with industry and community interests. It is difficult to argue that such an activity would take priority over filling obvious data gaps in the North, however.

Work on the vulnerability of coastal areas to flooding would benefit from a clarification of DFO's role. While some elements of this issue are best addressed by other agencies, DFO could play an important role in providing water-level forecasts and addressing the effects on coastal productivity, particularly in areas where wetlands may be flooded or created. Effects of erosion and periodic inundation on coastal infrastructure, such as wharves, jetties, and breakwaters, are another area of concern for parts of the Department, while other agencies are most concerned about the effects on municipal infrastructure. DFO's level of scientific effort directed towards natural disasters has probably declined overall in the last decade, and a review of the Department's role in this area would be welcomed by other agencies.

The Insurance Bureau of Canada has set up an institute in Montreal, with annual funding of about $1,500K, to look at catastrophic losses from natural disasters. This sector's top priority is forecasting the economic effects of earthquakes and storm surges in the Vancouver area. A link to flood-risk mapping and modelling is an opportunity for the 5NR departments.

Environment Canada and Natural Resources Canada

Environment Canada is moving towards the use of multiple climate change scenarios to forecast the range of risks to natural resources and industrial sectors. For Canadian fisheries, EC would like to understand on a very broad scale the impacts of projected changes in climate on fisheries in Canada. They need to know the major concerns and the thresholds for change at a regional scale. In particular, EC would like to know the triggers and where ecosystems are the most sensitive. This knowledge would help the Department define dangerous interference in the climate system, which Canada has a responsibility under the Kyoto Convention to address. DFO's response could include an assessment of the degree to which some of the key triggers will be expressed at the ecozone or ecodistrict scales.

EC would also like to see an increase in work on adaptation, particularly in the fisheries sector. What are viable adaptation mechanisms? Is aquaculture an Adaptation strategy for the Canadian industry? Can we understand the adaptive capacity of the fishing community? If there is a change in the fishery, what is the adaptive capacity of the fishing community? At what points can that adaptive capacity be influenced? How do we go about making these changes, both socially and economically?

Environment Canada has partnerships with three universities to pursue research on climate impacts and adaptation in Canada: UBC (Sustainable Development Research Institute), University of Toronto (Institute for Environmental Studies), and Waterloo (Faculty of Environmental Studies). The interests of this network, called the Adaptation and Impacts Research Group (AIRG), are both broad and diverse.

The AIRG at Waterloo is focussed on the Great Lakes/St. Lawrence Basin. The group at U of T has no coastal or ocean-related projects underway, although their interests include natural hazard risk assessment. The AIRG at UBC has had more interaction with DFO. They perceive that the Department is doing some of the research needed in basic biology, but is not taking the extra step to talk about the fishery management implications. Fisheries management is seen to have a strong social and economic component, with Adaptation work thus being an extension of social sciences that requires collaboration with biologists. More collaboration is also needed between scientists and management and between management and the fishing constituency.

The AIRG at UBC has had positive experiences by showing the output of climate change forecasts to individual community representatives and industry practitioners. They found this a useful way to take advantage of local and traditional knowledge, and see willingness among ordinary people to participate in this type of dialogue. These discussions will help to establish information needs and gaps.

Natural Resources Canada has program links with DFO, especially for research in the Atlantic Geoscience Centre and the Pacific Geoscience Centre.

Conclusions

1. At the scientist level, there is considerable interest in pursuing research on the impacts of climate change. There is less identifiable activity, however, and many scientists appear to be waiting for a signal from management (i.e., direction or funding) that the topic is important enough to warrant spending their scarce time. Decision-makers will require information about impacts and adaptation on a more or less continuous basis to manage and conserve the resources that are part of the Department's mandate. Many of the attributes that scientists say need to be better understood, and the models that need to be developed to understand and predict the impacts of climate change on marine resources and sectors, are the same attributes and models that need to be studied and developed if DFO is to move past a single species/ single stock management approach to an ecosystem-based management approach.

2. While support for Impacts and Adaptation science is evident at the scientific level, the job jar is full. The shift from species management to ecosystem management will not happen all at once, meaning that both types of work will have to proceed in the short term. The implication is that the Department needs to augment its biological staff to make significant progress. To address the issue in paragraph (1) in the short term, DFO should consider a two-pronged approach to allocating funds for climate research:
    - Targetted allocations to enhance the work of its scientific staff in all branches, where small increments might have significant benefits.
    - Hiring new scientific staff, especially to support advances in ecosystem modelling.

3. The level of activity in Adaptation science in DFO is low. Although in one sense it might be premature for DFO to be doing much work in this area, given the relatively poor understanding of impacts nationally, some work in each region could still usefully be done. The industry has already begun to make decisions, e.g., on new vessel construction, that take ocean climate impacts into consideration, and the concerns and information needs of the various industry sectors could be reflected formally in DFO programs. This remains an opportunity for development.

4. It has been difficult to quantify the level of effort presently expended on Impacts science. Stock assessment scientists across the country are doing related work around the fringes of their core responsibilities. In marine and freshwater, the relationships between biological and environmental variables (e.g., temperature) are being explored to help explain interannual variations in survival and recruitment. There is perhaps at least as much personal effort going into this area as there is into projects whose primary role is Impacts science.

5. For many of the species worked on by DFO, the knowledge of species biology is insufficient to begin CIA work. This is particularly a problem in Canada's North, where the changes may be the greatest. Basic biological research can provide information about habitat requirements and can contribute to management strategies, as well as providing a foundation for Impacts science.

6. There appears to be a need for closer ties between ocean modellers and CIA scientists in at least some Regions. Benefits could include better predictions and the alteration of monitoring

and other data collection programs. Improved dialogue would provide data to ocean climate models and to the ecosystem modelling on which Adaptation science depends.

7. The storm surge that hit parts of Atlantic Canada on January 23, 2000, is perhaps a harbinger of things to come. Better forecasting could have prevented some of the financial losses caused by this event. Given the responsibilities of the Oceans Program for coastal issues and the activities of CHS related to water levels and tidal forecast models, DFO should reassess its role in providing information that would improve natural disaster forecasting in Canada.

8. DFO has proposed participation in a renewal of GLOBEC funding for a further four years. As is presently the case, this funding is likely to be an important component of the resources available for CIA activities in Science Branch. Plans for the second phase of GLOBEC include improvements to the basic box models of biology that are presently embedded in physical oceanographic models. It is unlikely that the Department will have complete and functioning ecosystem models at the end of the second phase, but the various modules available from GLOBEC and other sources should provide considerable insight into ecosystem sensitivities and vulnerabilities.

9. Given all of the needs identified, there is a real risk that DFO could spread itself too thinly by tackling too many problems at the same time. A focussed approach is needed, for which a first step might be to cluster needs by region and by scope. A limited set of needs, linked by scope and linked nationally, would provide the Department with a framework for the next phase of CIA scientific activities.

10. Future science activities should address three components of CIA work important to DFO:
    - Basic biological research, where the need has been determined from the hints provided by scientific insight, retrospective analysis, and statistical, mass balance, and numerical models.
    - Biological modelling and other work whose purpose is to help determine the sensitivity and vulnerability of ecosystems (i.e., Impacts science).
    - Work to convert a range of impact scenarios into economic and social effects, and then to help communities and sectors adjust to the changes foreseen (i.e., Adaptation science).

    None of these three areas can prudently be neglected, implying that DFO should develop a scheme for apportioning the available resources.

Table 1. People contacted to obtain information for this report. Affiliation is DFO, unless noted.

Name	Function	Location
Dick Beamish	Research Scientist	Nanaimo
Peter Bein	AIRG, UBC	Vancouver
Paul Bellemare	Director-General, CCG	Ottawa
Lianne Bellisario	AIRG, U of T	Toronto
Marty Bergmann	Science Coordinator	Winnipeg
Jim Boutillier	Head, Invertebrates	Nanaimo
Robin Brown	Head, Ocean Sciences & Productivity	Sidney
Jim Carscadden	Head, Pelagic Fish	St. John's
Stewart Cohen	AIRG, UBC	Vancouver
Ken Drinkwater	Research Scientist	Dartmouth
Paul Egginton	Science Advisor, NRCan	Ottawa
Paul Fanning	Fisheries Biologist	Dartmouth
Ken Frank	Research Scientist	Dartmouth
Jacques Gagné	Head, Fish and Marine Mammals	Mont-Joli
Stratis Gavaris	Research Scientist	St. Andrews
Julian Goodyear	A/Director, CCG	Ottawa
Jim Helbig	Manager, Environmental Sciences	St. John's
Rick Herfst	Director, Canadian Institute for Climate Studies	Victoria
Stuart Innes	Research Scientist	Winnipeg
Rob Macdonald	Research Scientist	Sidney
Steve Macdonald	Head, Freshwater Habitat Science	Burnaby
Dave Mackas	Head, Ocean Ecology	Sidney
Ian Marr	Director, Icebreaking, CCG	Ottawa
Ken Minns	Program Leader	Winnipeg
Jean Munro	Chief, Habitat Sciences	Mont-Joli
Savi Narayanan	Director, MEDS	Ottawa
Charlie O'Reilly	Tidal Officer	Dartmouth
Michael Papst	Manager, Arctic Research	Winnipeg
Brian Penny	Supervisor, Operations	St. John's
Ian Perry	Research Scientist	Nanaimo
John Pringle	Head, Environmental Sciences	Sidney
Dave Reddin	Research Scientist	St. John's
Jim Reist	Head, Arctic Fish Ecology	Winnipeg
Bob Rutherford	Oceans Program	Dartmouth
Mike Sinclair	Regional Director	Dartmouth
Pablo Sobrino	Director, CCG	Vancouver
Roger Street	Director, EC	Downsview
Jean-Claude Therriault	Research Manager	Mont-Joli