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Aquatic Monitoring in Canada

A Report from the DFO Science Monitoring Implementation Team

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Chair

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TABLE OF CONTENTS

Foreword

DFO has lead responsibility for the Government of Canada in monitoring Canada's three oceans and freshwater habitats. In conjunction with a review of its science programs, the National Science Directors Committee (NSDC) requested a review of aquatic monitoring activities in early 2005. In May, a Monitoring Implementation Team (MIT) team was formed to assess the current level of monitoring effort, to identify what specific monitoring would be needed to support the overall science program and to identify areas needing improvement in addressing the various priorities. Members of the team were from headquarters and each of DFO's six regions.

The team conducted its work in three phases: 1) Review aquatic monitoring programs and prepare a framework for assessing current activities and areas needing increased or reduced levels of effort. This work was presented to NSDC in June 2005. 2) Assess delivery models for Atlantic, Pacific, Arctic, fresh waters and Pacific salmon; identify the regional role in monitoring; and, consult with regions and sectors for their input into a national aquatic monitoring program. This work was presented to NSDC in September 2005. 3) Complete analyses of lower priority areas, resources available for monitoring and activities that could be realigned; complete costing analysis of new monitoring activities that require more investment; develop a new national monitoring program, incorporating a revised vessel plan; develop a set of standards and protocols for national monitoring programs; and, complete a communications plan. The latter two items were not completed. The remaining material was presented to NSDC in November 2005 and to the Departmental Management Committee in February 2006.

This report comprises a summary of the information presented to NSDC. Brief overviews of the history of monitoring in the five target areas are also included. The team met twice, in May and October, but otherwise conducted its business in a series of bi-weekly phone calls. The work was shared among team members, who were as follows (specialty and region are in parentheses):

Doug Bancroft (oceanography, climate, Headquarters)
Bill Brodie (stock assessment, Newfoundland)
Robin Brown (oceanography, data management, Pacific)
Ghislain Chouinard (stock assessment, Gulf)
Andrew Cooper (stock assessment, Headquarters)
Ken Frank (oceanography, stock assessment, Maritimes)
Dominique Gascon (stock assessment, Quebec)
[1]Scott Millard (freshwater ecosystems, Central and Arctic)
[1]Michael Turner (freshwater ecosystems, Central and Arctic)
[2]Marty Bergmann (freshwater ecosystems, Central and Arctic)
[2]Bob Randall (freshwater ecosystems, Central and Arctic)

[1]Participated in phase one of report.
[2]Participated in phases two and three of report.

The following people also provided contributions to the report: Susan Bower, Susan Cosens, Chuck Parken, Ted Perry and Brian Riddell.

Michael Chadwick, Chair of the Monitoring Implementation Team

1. Executive Summary

During 2005, DFO Science conducted a review of its aquatic monitoring programs with the objective of identifying areas needing improvement, new requirements and where savings could be made. Monitoring provides the underpinning for all science advice provided by the department. About two thirds of the 56M spent by DFO on aquatic monitoring is invested in activities that support sustainable fisheries and aquaculture. The remaining third is invested in monitoring to maintain healthy and productive aquatic ecosystems. Partners spend an additional 30M on monitoring, mainly for fish stocks, particularly on the Pacific coast.

The area requiring the most improvement is monitoring in the Arctic and Canada's large boreal region. There are few systematic monitoring programs of ecosystem health, particularly in near-shore, coastal areas. Fish habitat, invasive species, food webs, species at risk, integrated management initiatives, marine protected areas and any effects of cumulative anthropogenic impacts are not well monitored. Almost all of our marine observations are made from ships, yet the number of available sea days has declined by half and the costs have doubled over the past two decades. Improvements could also be made with information access and integration. The public lacks information on the importance of aquatic monitoring and how it provides information on climate warming, loss of biodiversity, and invasive species. Currently, aquatic monitoring comprises a collection of regional initiatives that in their sum create the beginnings of what could be a national program. This type of approach is vulnerable to erosion of support funding.

There are a number of potential avenues to address areas needing improvement. First, new technologies, such as automated drogues for collecting physical and chemical properties of the sea, could be used to partly offset the loss of sea days. The Government of Canada fleet could also conduct more monitoring if equipped with appropriate data gathering instruments. Second, partnerships could be expanded. Monitoring, however, is a long-term investment and the role of charities, academics and governments needs to be clear. Fisheries sampling is one potential area for more partnerships. Third, protocols for data acquisition, archiving and access could be improved. Fourth, a standardized reporting of aquatic ecosystems could be implemented nation-wide. Ecosystem report cards would help to identify any shortcomings in monitoring as well as improving the state of knowledge. Fifth, there needs to be a clear commitment towards a national monitoring program to ensure that there is no further erosion of resources. Finally, monitoring requires a higher profile among the science-based federal departments. Lately, there has been emphasis on innovation, excellence, creativity and new technologies, but it could be argued that these themes fall more into the domain of universities, whereas knowledge of the state of Canada's environment would be more the responsibility of federal science and technology departments. A visible aquatic monitoring program would be key to meeting this objective.

2. Recommendations

Recommendation 1 – National Aquatic Monitoring Program

We need to establish a well-defined and integrated national aquatic monitoring program. A useful model is the Atlantic Zone Monitoring Program and its link to the national, Marine Environmental Data Services.

Recommendation 2 – Commitment

Before any action can be made towards establishing a National Aquatic Monitoring Program, we need to clearly define a long-term commitment to a sustained-level of funding and deliverable sea days for monitoring. Current monitoring is conducted mostly piece-meal in different parts of the country.

Recommendation 3 – Ocean Action Plan

Phase II of the Oceans Action Plan must include a sizeable investment in monitoring. The current phase includes no additional monitoring for any of the five Large Ocean Management Areas or the eleven Marine Protected Areas, which for the most part were established to protect unique marine resources, yet without any investment in monitoring.

Recommendation 4 – Communication

We need to improve the coordination and visibility of current monitoring activities across the country. The preferred approach would be to increase the presence of ecosystem indicators and monitoring products on the Internet. A good location for these products would be the website of the Canadian Science Advisory Secretariat. Moreover, a communication strategy would be required to adequately communicate monitoring activities to non-scientific audiences, many who live in remote areas of Canada without reliable Internet services.

Recommendation 5 – Shared Responsibility

We need to integrate the work on monitoring at different federal and provincial agencies into one national program and ensure that there is no duplication of effort. This step will require clarification of the inter-agency role with respect to monitoring. Currently, there is much confusion with regard to contaminants, an important topic for many Canadians.

Recommendation 6 – Quality Assurance

All monitoring programs require a structured approach to well-defined protocols for data acquisition, archiving and access. The merit and utility of any monitoring programs that continue without clear protocols for data management need to be critically examined.

Recommendation 7 – New Monitoring Needs

1. **The North**. Many of Canada's northern areas are not adequately monitored. We need to specify what level of monitoring is required and the DFO responsibilities.
2. **Species at Risk.** This legislation requires objective evaluations of distribution, habitat requirements and abundance. It is imperative that some of the SARA funding is directed towards monitoring.
3. **Oceans Act.** Investment in long-term monitoring needs to be explicitly identified in Large Ocean Management Areas and Marine Protected Areas. Long-established monitoring sites should be considered as potential candidates for any future MPAs.
4. **Coastal Zones.** There is very little systematic monitoring of Canada's coastal and littoral zones, which are key habitats for many aquatic species.
5. **Secondary Production.** We have great difficulty understanding changes in secondary production and their role in aquatic food webs in different regions of the country.
6. **Invasive Species.** We need to carefully review if existing surveys (primarily designed to estimate biomass of abundant species for assessing harvest potential) are appropriate for detection/tracking of rare species. We also need to review whether we have the required taxonomic expertise.

Recommendation 8 – Areas for Improvement

1. **New Technologies**. We need to explore potential opportunities for replacing existing monitoring programs with new technologies. Small autonomous profiling submarine robots are one example.

2. **Partnerships**. We need to develop more partnerships with universities on monitoring. Together we could develop strategic proposals to assess past and current monitoring activities for their role in understanding ecosystem changes; develop novel technologies; and, re-sample locations established in earlier programs, such as the International Biological Program.
3. **Single-species Surveys**. We need to establish a level of standards, identifying the minimum frequency and survey protocols by which we would conduct, fund or support a fishery monitoring survey. These surveys can be expanded to collect more information on ecosystem attributes.
4. **Sentinel Fisheries**. These surveys could be partially re-directed towards monitoring activities that contribute more information on ecosystem status.
5. **Fisheries Sampling**. We need to evaluate any duplication between Fisheries and Aquaculture Management, Policy and Economics, and Science in observer programs, logbook data, port sampling, quota monitoring and commercial sampling. We need to develop best practices, standardized procedures and improved on-line data entry systems before this activity can be further divested to industry.
6. **Fish Counting Traps**. We need to evaluate the investment on monitoring of migratory movements of Atlantic salmon in Atlantic Canada. Activities need to be rationalized among the regions.
7. **Government of Canada Vessels**. There is a large investment in keeping ships at sea for security and safety. We need to develop a new policy allowing these vessels to undertake a secondary tasking for monitoring purposes.
8. **Ecosystem Status Reports**. We need to establish a formal framework to produce these reports in a regular manner for all aquatic ecosystems across the nation.
9. **Communications**. DFO monitoring programs are not visible and need to be clearly communicated, with an emphasis on the importance of long-term time series.

3. Objectives

The monitoring implementation team was asked to prepare five items:

1. Delivery models for five areas: Arctic, Atlantic, fresh waters, Pacific, and Pacific salmon.
2. Feedback from consultation with regions and sectors.
3. A presentation that can be used to consult with other federal departments and research institutions.
4. An analysis of low-priority areas that has been coordinated with the Stock Assessment and Data teams.
5. A complete costing and source of funds for any new activities.

Members of the team were: Michael Chadwick (chair), Doug Bancroft, Marty Bergmann, Bill Brodie, Robin Brown, Ghislain Chouinard, Andrew Cooper, Ken Frank, Dominique Gascon and Bob Randall. The following people also provided contributions to the report: Susan Bower, Susan Cosens, Scott Millard, Chuck Parken, Ted Perry, Brian Riddell and Michael Turner.

4. Purpose of Monitoring

4.1 Link to federal mandate

DFO's scientific monitoring programs are conducted to support the sustainable development and safe use of Canadian waters. These monitoring programs are as germane to managing Canada's aquatic resources as monitoring of expenditures would be to the management of any budget. They are linked to the legislated obligations of the Government of Canada. They also provide basic information to measure progress on the delivery and performance of DFO's three strategic outcomes, which are listed below with the federal mandates and how DFO Science responds to them:

1. Safe and Accessible Waterways (SAW)

- The Charts and Nautical Publications Regulations, 1995, of the *Canada Shipping Act* specifically requires all vessels to carry and keep up-to-date Canadian Hydrographic Services charts and related publications.

  Science responds by:
  - Providing products and services for navigation; and,
  - Assessing the impact of climate variability.

2. Healthy and Productive Aquatic Ecosystems (HaPAE)

- Section 20 of the *Fisheries Act* that requires the Minister to ensure that obstructions across streams permit the free passage of fish.
- Section 35 of the *Fisheries Act* prohibits the harmful alteration, disruption or destruction of fish habitat.
- Section 36 of the *Fisheries Act* prohibits the deposition of deleterious substances into water frequented by fish.
- Canada's *Oceans Act* (enacted 1996) confirms DFO's obligation to work collaboratively with interested Canadians in developing and implementing a national strategy for the management of the three oceans and coastal areas.
- Canada's commitment to the United Nations Conference on Environment and Development to create a global system of ocean observations to understand the precise nature of the ocean's role in controlling climate change
- The Minister is required to protect aquatic species and their habitats listed under the *Species at Risk Act* (SARA).
- The Minister is required to meet his obligations under the *Canadian Environmental Assessment Act.*

  Science responds by:
  - Assessing impact of development on aquatic ecosystems;
  - Assessing aquatic ecosystems and supporting integrated oceans management;
  - Supporting the assessment and recovery of SARA species in the aquatic environment;
  - Determining the role of oceans in global climate; and
  - Assessing the impact of climate variability.

3. Sustainable Fisheries and Aquaculture (SFA)

- The *Fisheries Act* requires the Minister to regulate fisheries, respecting the conservation and protection of fish.
- In 1999, Canada became a signatory to the *United Nations Fish Stock Agreement* (UNFSA). UNSFA came into effect in December 2001. As such, under Article 14, countries need to ensure that data are collected in sufficient detail to facilitate effective stock assessment and are provided in a timely manner.
- *Fish Health and Protection Regulations* prohibit the importation of cultured fish or eggs of wild fish without a permit.

- *Management of Contaminated Fisheries Regulations.*
- The Minister is required to respect the following international obligations: North Atlantic Fisheries Organization, Pacific Salmon Treaty, North Atlantic Salmon Organization, Great Lakes Fisheries Commission, International Commission for the Conservation of Atlantic Tuna, Trans-boundary Advisory Committee (Gulf of Maine) etc.

  Science responds by:
  - Assessing the status of fishery resources;
  - Preventing and controlling aquatic invasive species;
  - Supporting sustainable aquaculture production;
  - Preventing and controlling aquatic animal diseases; and,
  - Evaluating interactions between aquaculture and the environment.

4.2 Definition of monitoring

Aquatic monitoring is the collection of scientific information in the marine and freshwater environments. When done in a sustained and systematic manner, monitoring can be used to inform public policy, make decisions in resource management and ensure health and safety for all Canadians. DFO's monitoring programs enable us to assess the state of Canada's aquatic resources and ecosystems against benchmarks. Without this monitoring, we would be unable to audit how well we manage Canada's aquatic resources. Our monitoring programs also provide an early-warning system and an understanding of aquatic ecosystems to help detect change and attribute cause.

There are several important principles that must be considered when evaluating DFO's monitoring programs. These principles are that the monitoring must be representative, have known accuracy, be available and accessible, understandable and cost-effective.

We considered dedicated monitoring to include all projects (2004-2005) meeting the following criteria: duration ≥ 5 years (and recently-implemented programs that have the potential to continue for > 5 years), science function ≥ 50% monitoring and DFO monitoring expenditure ≥ $10,000. Partnership monitoring included the same criteria, except the partnership expenditures were ≥ $10,000. We note that this definition includes projects that might be better described as "long-term research" programs that are many years long, but which we do NOT intend to continue more or less "forever". Projects in this category include such items as the sea-lice program in the Pacific.

4.3 Kinds of monitoring

DFO conducts about 25 different kinds of monitoring activities. For complete descriptions see Table 1. The activities can be roughly divided among the three strategic outcomes: Safe and Accessible Waterways, Healthy and Productive Aquatic Ecosystems, and Sustainable Fisheries and Aquaculture. It must be understood that many monitoring activities support multiple objectives. Multi-species surveys, for example, tell us a great deal about the ecosystem in physical and biological terms, and are one of the most important sources of information for listing species under the *Species at Risk Act*; as such, they could be coded under HaPAE. Nevertheless, because these surveys were originally designed to provide fishery-independent abundance indices for key commercial species like cod, they are coded under the SFA strategic outcome. Sections and fixed stations also serve several outcomes. These activities were first designed to understand ecosystem changes and are coded under HaPAE. They are also used to observe density and temperature of seawater, which are then used to estimate water level and thickness of sea ice for navigation, SAW activities.

Types of monitoring by strategic outcome (SAW - Safe and Accessible Waterways; HaPAE - Healthy and Productive Aquatic Ecosystems; SFA - Sustainable Fisheries and Aquaculture).

1 - SAW	**2 - HaPAE**	**3 - SFA**
Monitoring of bathymetry and water level	***Monitoring of ecological integrity and biodiversity***	***Monitoring of population abundance, distribution and health***
Bathymetric surveys (repeated surveys only)	Contaminant monitoring	Age and growth labs
Water level gauges	CPR lines	Fish counting facilities
	Diet surveys	Fish health surveys
	Fixed stations	Fisheries sampling
	Other monitoring activities	Multi-species river surveys
	Plankton, larval, juvenile surveys	Multi-species trawl surveys
	Satellite, remote sensing	SCUBA surveys
	Sections	Sentinel surveys
	Ships of Opportunity	Single-species surveys
	Short-term, issue-driven monitoring	Tagging and genetics
	Taxonomy & reference labs	Toxic algae
	Technical support & equipment	
	Thermographs	

In addition, there are short-term-issue monitoring projects under all three strategic outcomes, which we have not examined in detail because they usually have dedicated funding.

5. Analysis of Delivery Models

This report examined five delivery models: Atlantic, Arctic, Fresh water, Pacific and Pacific salmon.

5.1 Atlantic

The Atlantic Zone Monitoring Program (AZMP) was implemented by four regions in five Atlantic provinces in 1998 with the aim of describing and understanding oceanic variability in the Atlantic zone. AZMP comprises seasonal sampling of physical (temperature, salinity), chemical (nitrate, nitrite, phosphate, silicate, oxygen) and biological (fluorescence, chlorophyll a) variables along 13 sections, higher-frequency sampling of the same variables at six fixed stations, single samples of the same variables from >1,000 locations in multi-species trawl surveys, remote-sensing of sea-surface temperature, ocean colour and primary productivity and data from continuous plankton recorder lines (Scotian Shelf and Western Atlantic), sea-level at nine locations, the long-term near-shore temperature monitoring network, harmful algae monitoring and meteorological data from Environment Canada. All data are validated, archived and accessible to the public at the following website:

http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html

Most of DFO survey data are carefully archived in databases at all Regional headquarters. There is typically no single source where one can view all the survey data, like AZMP, due to the variety and many uses of the data. Usually, survey results are found in research documents of the Canadian Science Advisory Secretariat (CSAS) and the Northwest Atlantic Fisheries organization (NAFO) which present details of stock assessments (for example, see http: //www.dfo-mpo.gc.ca/csas/Csas/DocREC/2004/RES2004_023_e.pdf). The survey data are also an important, and sometimes the only, source of biological data for numerous studies published in the primary literature (for example, http://article.pubs.nrc-cnrc.gc.ca/ppv/RPViewDoc?_handler_=HandleInitialGet&journal=cjfas&volume=62&calyLang=eng&articleFile=f05-065). The multi-species surveys also provide important sources of oceanographic data over wide geographic areas, and these data are often combined with other AZMP data to produce regular overviews of ocean conditions (for example, see

http://www.dfo-mpo.gc.ca/csas/Csas/status/2004/ESR2004_001_e.pdf).

The main areas for improvement in the Atlantic zone are: inadequate sampling of benthic and pelagic communities; the absence of systematic sampling in the near-shore coastal areas; lack of monitoring in the north, including Labrador; and the inability to complete bi-weekly sampling at most fixed stations. Nevertheless, AZMP is clearly the model that should be considered for other parts of the country.

5.2 Arctic

A comprehensive monitoring program needs to be developed for the Arctic. Because this northern area is served by five regions, it is important that activities are well coordinated. The AZMP provides a good framework to begin this work. It is unlikely that annual multi-species trawl surveys would be required.

Currently, oceanographic monitoring has been conducted opportunistically in national and international research programs (Surface Heat Budget of the Arctic Ocean (SHEBA), Northern Water Polynya Project (NOW), Canadian Arctic Shelf Exchange Study (CASES), Joint Western Arctic Study (JWACS)). These programs have specific objectives (e.g. climate change, ocean currents etc.), and are relatively short term but have allowed the collection of valuable scientific information in specific geographic locations of the Arctic.

Recently, DFO scientists have been collaborating with academia in ArcticNet which has a number of projects that will monitor changes in Canada's Arctic environment. This research and monitoring will cover different regions under various themes. Funding for this initiative has been secured for seven years, and is renewable for another seven. It will be important for DFO to consider programs like ArcticNet when developing its long-term monitoring initiatives.

Along with the need to develop a comprehensive monitoring program for the Arctic, is the need to recognize legal obligations under northern land claim agreements for co-management of fishery resources. Requirements under these agreements include the need to involve communities in monitoring of coastal fish resources (fish and marine mammals) using a community-based monitoring approach.

International Polar Year (IPY) may provide an opportunity for developing a long-term monitoring program for Canada's Arctic as its legacy.

5.3 Fresh water

On the east coast, DFO monitors the abundance of adult and juvenile Atlantic salmon (*Salmo salar*) annually at a number of index river sites in New Brunswick (e.g., Miramichi, Restigouche), Nova Scotia (e.g., Margaree) and Newfoundland (e.g., Western Arm Brook). In Québec, similar index monitoring (e.g., Trinité) is conducted by the Province. In the Maritimes, catches of other diadromous fishes such as gaspereau (*Alosa* spp.) and striped bass (*Morone saxatilis*) are also recorded at index stations. The number of monitoring sites is reduced from what was done historically; data from the remaining strategic sites are critical for zonal stock assessment of diadromous species. On the west coast, the abundance of Pacific salmon (*Oncorhynchus* spp.) is also monitored in fresh water by DFO to support stock assessment, as reported in section 5.5.

In the Great Lakes, DFO is responsible for the sea lamprey (*Petromyzon marinus*) control program in Canadian waters. The lamprey program is managed jointly by the Canada-United States Great Lakes Fishery Commission (established by the *Great Lakes Fisheries Convention Act)*. Within DFO, the sea lamprey program became part of the Science Sector during Program Review (formerly, the program was controlled by Habitat Management). While the primary objective of the program is to control the sea lamprey, two types of monitoring are conducted annually: i) ammocoete larval surveys (electrofishing) to determine the location of control sites; and ii) adult spawner surveys to determine the success of the lamprey control program. Success is also monitored by directed mark-recapture programs using coded wire tags (CWT) and wound counts (data provided by the province).

Bay of Quinte, located in northeastern Lake Ontario, is the site of a long term monitoring study (1972 to present) to determine the impact of human activities on the status of this ecosystem and to evaluate the success of remediation. As part of a multi-agency study to address the goals of the Great Lakes Water Quality Agreement, DFO led the monitoring of lower trophic levels throughout the bay (macrophytes, benthos, phytoplankton and zooplankton). Historically, this monitoring was initiated to address water quality issues (eutrophication), but more recently the ecosystem monitoring is to address DFO priority issues of impacts of development on fish habitat, invasive species and the need for integrated ecosystem management for sustainable fisheries. Similar monitoring has recently been initiated in Hamilton Harbour.

In the past, extensive whole-lake monitoring of all lower trophic levels was undertaken in lakes Ontario and Erie (BioIndex Program), and elsewhere in the Great Lakes, but these surveys have been discontinued. Reduced monitoring of key food web species (mysids and Diporeia) continues but is inconsistent spatially and temporally. A comprehensive long-term monitoring program of contaminants in Great Lakes food webs (including fishes) was also conducted by DFO for 29 years, but this program will not be funded after 2005 (See Section 8).

In more northern areas of central Canada, long term monitoring is conducted at a few locations to support DFO's assessment or science mandate. The Experimental Lakes Area has a 30-year record of hydrological, meteorological, chemical and biological data for a number of natural "control" lakes. In addition to providing control data for specific science projects, the monitoring data are used to address other issues such as the impact of climate change on the ecology of Canadian Shield lakes. DFO is also a partner in the Turkey Lakes Watershed Study, led by Environment Canada (//www.TLWS.ca). In the Northwest Territories and Nunavat, fish populations are monitored at Great Slave Lake (Fishery Vessel Observation Program, commercial lake whitefish), Tathlina Lake (commercial lake whitefish), Kakisa Lake, and Cambridge Bay to support fisheries, depending on location, for lake whitefish (*Coregonus clupeaformis*), inconnu (*Stenodus leucichthys*), walleye (*Sander vitreus*), lake trout (*Salvelinus namaycush*) and anadromous char (*Salvelinus alpinus*). The monitoring frequency varies depending on the location, objectives and funding (e.g., Aboriginal Fisheries Strategy Fund). Upstream weir counts of anadromous char at Cambridge Bay were conducted in the past but are not planned for the future (although needed) because of lack of funding. Similarly, a monitoring program for the walleye recreational fisheries at Mosquito Creek is not currently ongoing. An established commercial plant sampling program for Cambridge Bay char fisheries is ongoing and a similar program is being developed for the Pangnirtung char fisheries; but both are supported by short-term funding (Nunavut Implementation Fund and Nunavut Wildlife Management Board). Other monitoring activities in the sub-Arctic have been short term and ad hoc to support specific research, management or regulatory responsibility (e.g., Mackenzie pipeline).

Monitoring water quality in the freshwaters of Canada is conducted or coordinated by Environment Canada and provincial agencies. To fulfill Canada's obligations under the Canada-United States *Great Lakes Water Quality Agreement*, EC conducts a surveillance program on the Great Lakes to monitor nutrients, major ions, organic contaminants, biological (chlorophyll a) and physical parameters. Elsewhere in the central, eastern and western regions of Canada, water quality in freshwaters is monitored by Environment Canada (particularly boundary waters), or in collaboration with other agencies (http://www.ec.gc.ca/water/en/links.cfm?category_id=4&sub_section_id=23).

To achieve comprehensive and accessible monitoring data for tracking biotic and physical parameters in fresh waters, a multi-agency database sharing program, similar to AZMP, is needed to cover all regions in a consistent manner (Atlantic, Great Lakes, central, Hudson Bay and sub-Arctic, and Pacific).

5.4 Pacific

The monitoring program aimed at describing and understanding oceanic variability for the Pacific Region is not as complete and as structured as that outlined for the Atlantic Zone Monitoring Program (AZMP).

Monitoring data are collected, analyzed and subjected to quality control before archival at regional centers. Selected data types (water property profiles, water level data) are sent to the national archive at Marine Environmental Data Service (MEDS). Results from some monitoring activities are regularly updated to publicly available web sites. Some examples are:

- Lighthouse data: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/Searchlighthouse_e.htm
- Line P data: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/linep/linepselectdata_e.htm
- Satellite Image Data: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/SearchSatellites_e.asp

Pacific marine fish survey data are collected for groundfish, invertebrates, pelagic species and mammals using a variety of vessel platforms and methods (e.g. trawl; hydroacoustics; dive). Much of the bridge-log and biological data are published in the Canadian Fisheries and Aquatic Sciences reports series. Analyses and results are reported in this series, CSAS documents and primary publications. These surveys are summarized below:

Groundfish

- West coast Vancouver Island (WCVI) groundfish bottom trawl survey aboard the W.E. Ricker, a new bi-annual mission that provides ecosystem information of assemblages along the continental slope < 500 m.
- Hecate Strait bottom trawl survey aboard the W.E. Ricker, a bi-annual mission since 1984 that provides ecosystem information of assemblages in Hecate Strait as well as species-specific information for commercially-harvested animals
- Queen Charlotte Sound groundfish bottom trawl survey, conducted with industry partners to provide species-specific information of commercially harvested animals. This biannual survey started 3 years ago.
- Coast-wide sablefish assessment and tagging survey, conducted annually since the mid 1980s with industry partners to provide species-specific information of commercially harvested animals.
- Hecate Strait Pacific cod monitoring survey is a series of surveys conducted annually since 2000 with industry partners to provide information for commercially harvested animals.
- Inshore rockfish surveys (jig, camera and submersible) a 3-year old program that has been implemented to address concerns about listing certain rockfish species under SARA.
- Inside lingcod surveys (larval, handline, and trawl), a 3-year old program that has been implemented to address concerns about the population status of inside lingcod populations and their likelihood of being listed under SARA
- Groundfish trawl observer program, funded jointly with industry, provides catch estimates of target and bycatch species. There is a 100% coverage of offshore vessels.

- Groundfish port sampling provides biological samples used in assessment of a number of commercial species. There is year-round port sampling in Prince Rupert and Vancouver.
- Hake coast wide assessment hydro-acoustic tri-annual survey done in partnership with the US National Oceanic and Atmospheric Administration (NOAA) to provide assessment of this commercial species.

Pelagics

- Herring spawn surveys and commercial sampling programs are conducted with industry to provide annual area and species-specific information for stock assessments.
- Fraser river eulachon assessment is conducted annually with First Nations and commercial partners. This species is being considered under SARA in certain regions of the coast.
- Offshore herring surveys are used to provide pre-fishery indices of new recruits animals.

Marine Mammals

- BC Steller sea lion survey conducted tri-annually in conjunction with other Pacific Rim countries to evaluate the status of this species which has shown major declines in Alaska resulting in their listing under the US species-at-risk legislation.
- A large whale survey is conducted annually as part of the SARA action plan for a number of these threatened and endangered species.
- An annual survey is conducted to study the population structure of SARA-listed resident killer whale populations.
- A sea otter survey has been conducted annually over the last 6 years in response to the listing and assessment of this SARA protected species.

Shellfish

- Shrimp-by-trawl surveys are a series of annual index surveys to assess a complex assemblage of 7 species of shrimp and there related ecosystems along the entire B.C. coastline. This program is jointly funded with industry and provides bases for the sustainable harvest of these species as well as determines the risks inherent in the by-catch of other species. Some of the components of this survey are longest time series of ecosystem assessments conducted on the BC coast (starting in 1973).
- Prawn-by-trap is an annual pre and post index assessment of the prawn fishery to evaluate the adequacy of the in-season assessment and management protocols for this fishery. In addition it provides an index of the changes to other components of the ecosystem. This is done in collaboration with the industry
- Prawn assessment of the commercial and sports fisheries is conducted with an at-sea observer program in cooperation with the fishery to insure that target reference points are not exceeded.
- Sea cucumber assessment and experimental fisheries are conducted annually with industry to provide information for the assessment and modeling of stock productivity.
- Geoduck and horseclam density and substrate mapping of some of the 1500 known exploited beds are monitored annually in collaboration with the industry.
- Red urchin surveys are conducted annually in conjunction with industry for stock assessment.
- Clam surveys are conducted with industry on commercially exploited beaches used for depuration.

- Clam multi-species and invasive species surveys are conducted biannually on selected beaches along the B.C. coastline.
- Goose barnacle surveys are conducted with industry for stock assessment.
- Scallop surveys are conducted with industry for stock assessment.
- Dungeness crab surveys of selected areas are conducted collaboratively with industry for stock assessment.
- Deep-water Tanner crab surveys are conducted systematically along the shelf slope between 500-2000 meters for stock assessment and to provide a fishery-independent assessment of potential impacts of fisheries activities on the ecosystem.
- Inshore Tanner crab surveys are an industry-funded program to provide information for stock assessment.
- Green urchin assessment and research surveys are conducted annually with industry for stock assessment.
- Abalone surveys are conducted annually in partnership with First Nations to assess the health and viability of various populations of this threatened SARA-listed species.

Monitoring data and research data are combined and used for an annual "State of the Ocean" report: http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm

5.5 Pacific salmon

Canada's substantial commitments to the monitoring, assessment, and management of Pacific salmon reflects the strong cultural, social, and economic values, both domestically and internationally, the ecosystem value of Pacific salmon, and the risks to them associated with human activities. Pacific salmon are a true icon for life in the British Columbia and the Yukon. These values have frequently resulted in the management of Pacific salmon being controversial. For example, competitive fishing between Canada and the United States has occurred for over a hundred years and finally resulted in the Pacific Salmon Treaty (1985, and re-negotiated in 1999). Within Canada, there is an equally long history of controversy between industries, different user groups including gear sectors of the commercial fishery, recreational fishers, and First Nations (over 200 in BC and the Yukon).

The challenge though is not just about resolving conflict in use and values, but also involves understanding the biology and diversity of Pacific salmon populations in BC and the Yukon. Pacific salmon return to their natal streams to reproduce and then die, and demonstrate a variety of adaptations to their natal stream habitats. This diversity was recognized early in the development of Pacific salmon biology and management, and was the basis for the development of the "stock concept" in Pacific salmon. Each local spawning population (i.e., each species/stream combination) could accumulate genetic variants important to their productivity and that should be protected in order to maximize the production of Pacific salmon. However, by this simple definition, approximately 8,500 "local populations" would be defined in BC and the Yukon, and management of this diversity was not possible given the distribution of fisheries and the pressure to fish.

Early in the 1900s, competition for salmon drove fisheries seaward from rivers into coastal waters where many populations were mixed in the catch. For example, troll fisheries for Chinook and coho salmon along the west coast exploit hundreds of populations of each species from wide areas of BC and the Pacific Northwest states; and often exploit fish at multiple ages including immature juveniles and mature adults. Mature salmon migrating along the coast to their natal rivers encounter sequential fisheries that have the capacity to over-exploit a return before the impact could be detected.

From a technical perspective, the early monitoring and management of Pacific salmon also lacked the theoretical model to determine how to sustain the resource. While commercial fishing was extensive by the late 1800s, the theory of stock recruitment (S/R) was not formalized until 1954 by Canada's prominent fishery scientist W.E. Ricker. The model hypothesized that the production of progeny (recruits to a fishery) was curvilinear with a maximum production expected at an “optimal” number of spawners in the parental generation (the ‘stock’). If the numbers of spawners exceeded the optimal value, the numbers of progeny produced was expected to decline due to competition on the spawning grounds or limits to juvenile growth and survival. This model subsequently dominated the assessment of Pacific salmon (i.e., determination of the optimal number of spawners and the sustainable exploitation rates) and established the management paradigm of achieving the maximum sustainable yield (i.e., the yield expected, on average, from a stock at the optimal spawning stock size, S_{msy}). DFO’s advice was focused on defining the S_{msy} for stocks and established S_{msy} value as a management ‘target’ (an early reference point). However, fifty years of assessment and management history has demonstrated that the information requirements to determine an unbiased production function are demanding (accurate spawning stock size, accounting for the total fishing mortality on the stock, stock identification tools to identify the stock of interest, biological sampling for age, and monitoring on environmental trends that effect the productivity of the stock’s habitat), and the management paradigm has not conserved the production or diversity of Pacific salmon.

In theory, the assessment and monitoring needs for Pacific salmon have not changed. However, a reality has developed that we must recognize uncertainties in stock assessment; examine the harvest management policies for the quality of data that can be expected, and to increasingly recognize the importance of environmental variation, ecosystem impacts, and necessity for diversity in salmon. The primary task of Pacific salmon stock assessment remains to advise fisheries management, Pacific Salmon Treaty members, First Nations, stakeholders, and the public on the status of the salmon resource. Status is a specific and technical term that means, simply, a comparison of estimated fish abundance to a desired abundance that would allow a pre-defined set of objectives to be met with some specified level of certainty. Stock assessment and monitoring functions can be interpreted as an integrated program achieving multiple objectives. The assessment of stocks is quantitative and therefore data-intensive. Because of the importance of data most of the activities that stock assessment staff are involved in deal with the collection of data and data-management. A much overlooked set of activities that is central to modern governance and dependant on monitoring is the interface between stock assessment and clients. The interface involves reporting, consultation, outreach (technical support), information exchange, and public relation functions.

Currently, within Pacific Region, 92 salmon stock groups (Assessment Units) are used for status summaries and monitoring. Of the seven Pacific salmon species, DFO monitors the abundance of sockeye, Chinook, coho, pink and chum salmon, whereas the province of British Columbia monitors anadromous steelhead and cutthroat trout. Among the 92 stock groups monitored by DFO, most are sockeye (29) followed by Chinook (24), coho (19), chum (11), and pink salmon (9). In June, 2005 however, DFO announced Canada’s Policy on the Conservation of Wild Pacific Salmon (WSP) that provides a framework for the conservation and sustainable use of wild Pacific salmon (http://www-comm.pac.dfo-mpo.gc.ca/publications/wsp/default_e.htm). This policy states an explicit commitment to conserve the diversity of wild salmon, define ‘benchmarks’ (reference points) to protect their status, establish assessment frameworks for each conservation unit of salmon, and recognizes the critical need for the protection and function of aquatic and terrestrial ecosystems. The health and long-term well-being of wild Pacific salmon is inextricably linked to the availability of diverse and productive freshwater, coastal, and marine habitats. In addition, the adoption of the Ocean’s Act commits the government of Canada to developing an oceans strategy for the management of marine ecosystems. The strategy and programs under the Act are guided by the principles of precaution, integrated management, and sustainability to ensure both present and future Canadians will enjoy the bounty and pleasure afforded by our oceans (Anonymous 1996). Monitoring of the status of habitats and freshwater ecosystems are primary means to achieve the goal of restoring and maintaining healthy and diverse salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity.

Monitoring of Pacific salmon has historically responded to the needs of managing and sustaining fisheries. The WSP and the Ocean’s Act, however, establish new standards and monitoring will again have to evolve. Most notable for Pacific salmon will be the need to assess the distribution of salmon in their landscape and development of indicators to assess the status of habitats and ecosystems. The WSP also recognizes the essential role of partners and the public in the successful conservation of

Pacific salmon. However, effective co-operation and co-management will place an extraordinary strain on Departmental information systems (timeliness, accuracy, availability) that, in the Pacific Region, will present a significant challenge.

6. Expenditures

The current distribution of resources spent in each area by strategic outcome and monitoring activity is provided below. DFO Science costs (about $56M) are in the first figure below. Partner costs (about $31M) are in the second figure, at the top of the next page. Data are also available in tabular format (Tables 2 and 3). In general, most monitoring is directed towards SFA and the least is devoted to SAW.

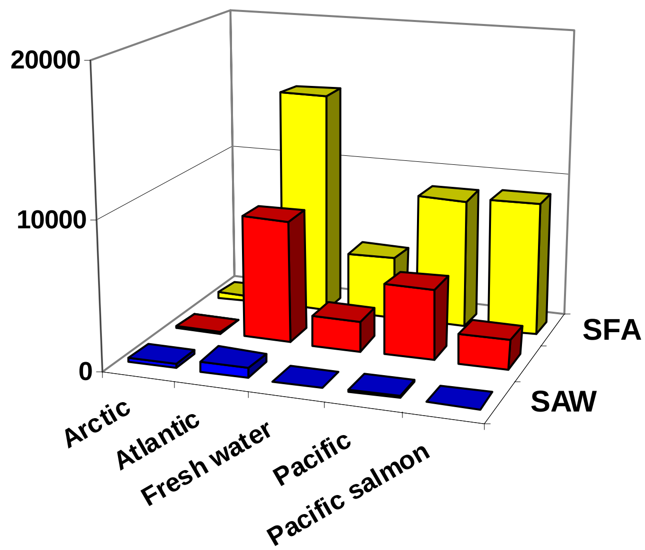

Figure 1. Expenditures (thousands of dollars) by DFO Science on monitoring.

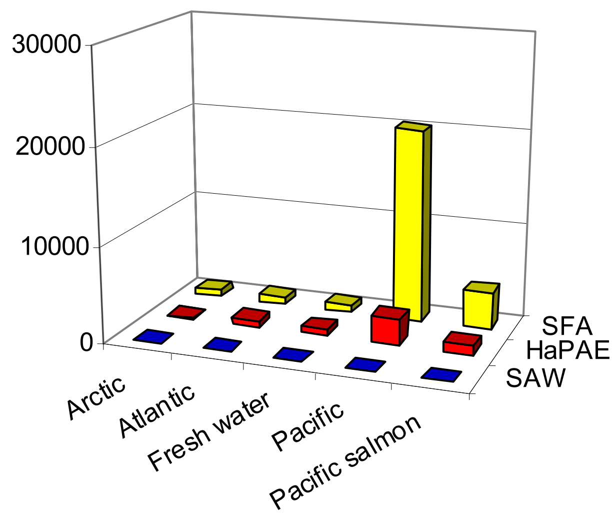

Figure 2. Expenditures (thousands of dollars) on monitoring by partners of DFO Science.

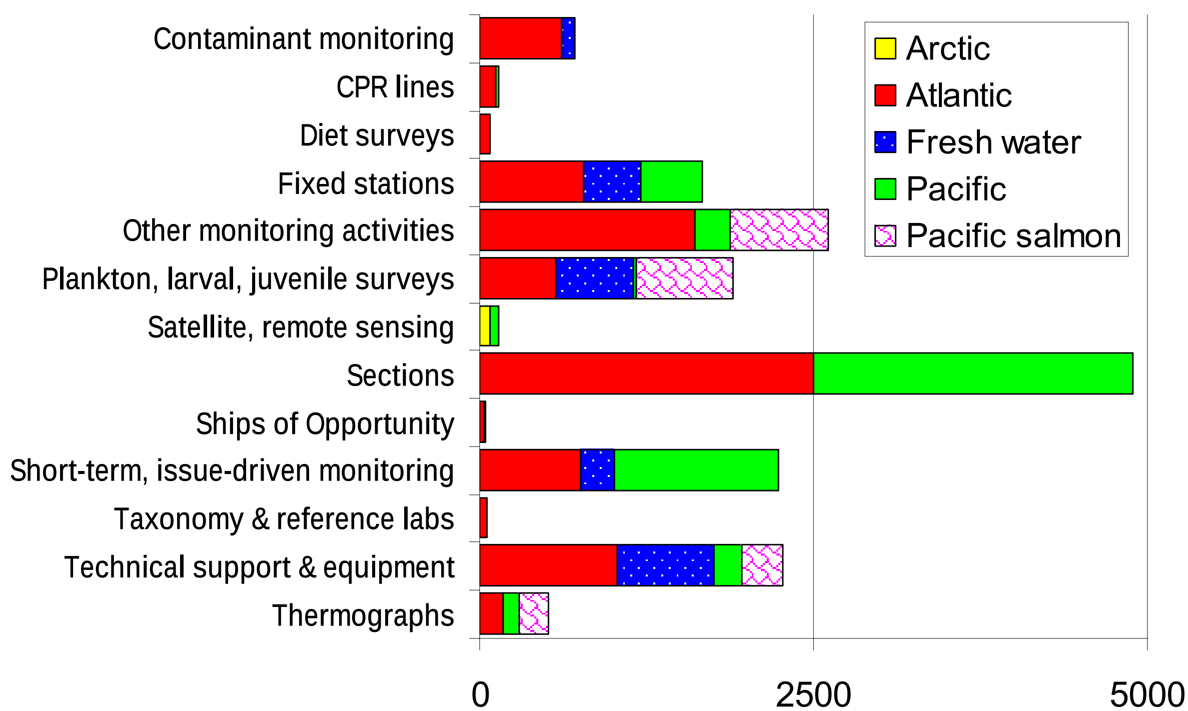

Figure 3. DFO Science monitoring expenditures (thousands of dollars) for activities related to the strategic outcome, Healthy and Productive Aquatic Ecosystems.

Oceanographic sections are the most expensive HaPAE monitoring activity, with almost equal investments in Pacific and Atlantic.

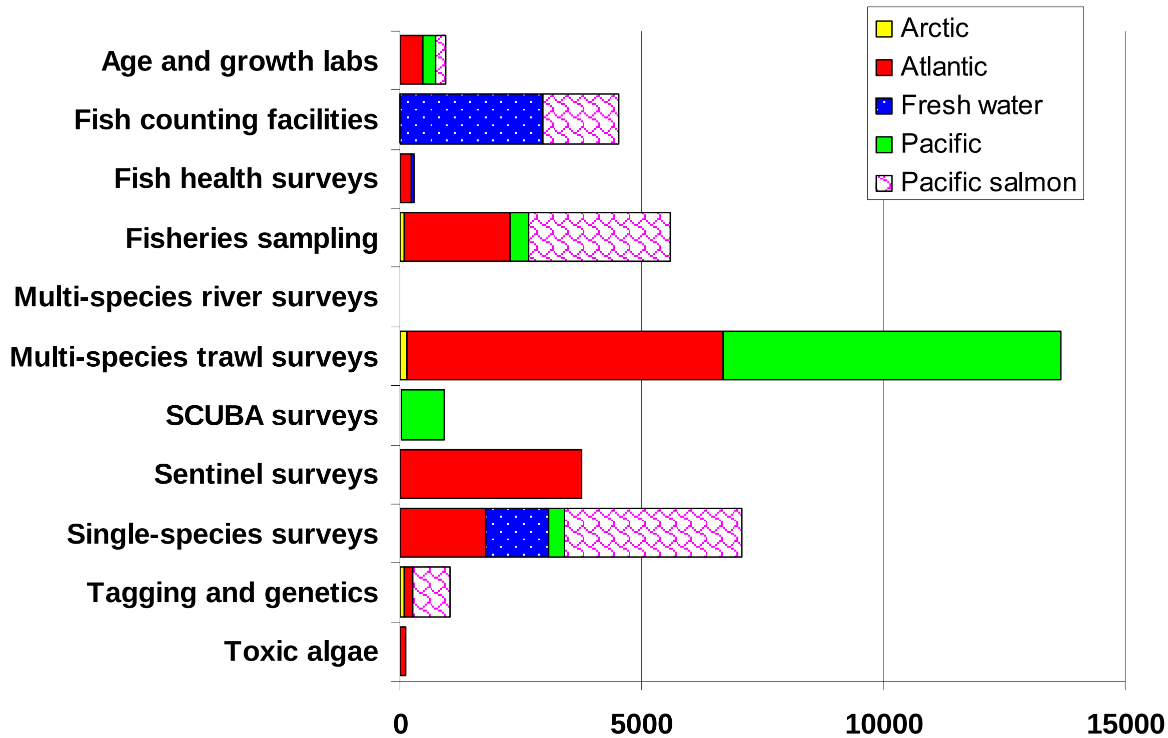

Figure 4. DFO Science monitoring expenditures (thousands of dollars) for activities related to the strategic outcome, Sustainable Fisheries and Aquaculture.

Most of SFA costs are for multi-species trawl surveys on the Atlantic and Pacific coasts. There is also a large investment in surveys and sampling of more than 5,200 spawning populations of five species of Pacific salmon.

7. History of Monitoring

Canada has a long history of aquatic monitoring. Discovery surveys in the early part of the last century were the catalyst for many of the long-term monitoring programs, many of which were begun because of the availability of ship time. In general, the 1980s saw the greatest utilization of sea days. Since these years, there has been a steady decline. The figure below shows the trend of decreasing sea days available for making marine observations. Since 1988, the number of sea days available on large vessels has declined by almost 50%.

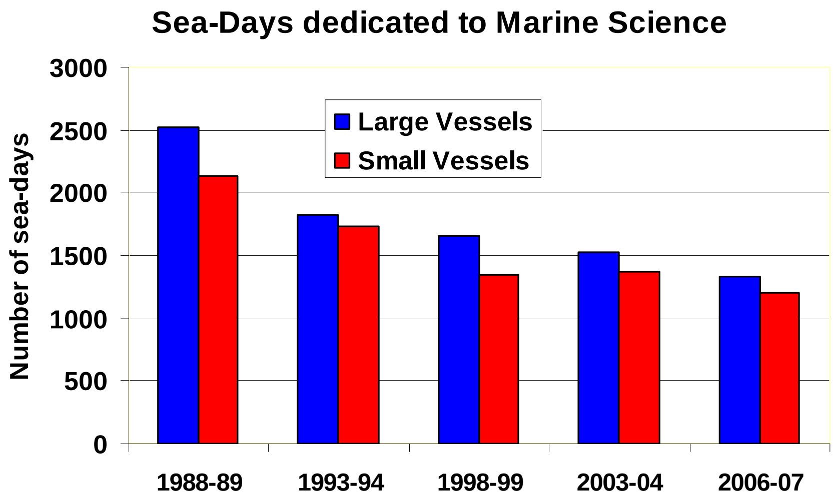

Figure 5. Number of sea-days dedicated to marine science by DFO.

This trend is also true for monitoring programs. By way of example, the following surveys and time series have been discontinued in the Atlantic:

- juvenile flatfish surveys on the Grand Bank 1985-1994 (some, not all, of this survey design has been taken up in the fall multi-species Campelen surveys, beginning in 1995)
- Flemish Cap surveys (1977-1985). At present only a small portion of Flemish Cap (deep area adjacent to Flemish Pass) is covered in the fall multi-species survey
- pelagic 0-group surveys on G Bank + NE NL Shelf – begun under the Northern Cod Science Program, discontinued in 2000
- capelin abundance in 2+3K, 3L, 3NO – acoustic surveys (offshore capelin work continues in 3L, but not in other areas)
- aerial surveys, beach surveys of spawning capelin
- scallops (surveys are now in 1 area every 3 years instead of each area every year)
- unit 2 redfish (some DFO surveys, some industry surveys). DFO has discontinued its surveys, discussions continue re. industry surveys
- 2H done every second year, 2G not at all
- herring acoustic survey in the northern Gulf (1989-2002) was discontinued, as were similar surveys in the NL Region
- northern Gulf of Saint-Lawrence multi-species winter survey (1978-1994) which was discontinued after various summer surveys were combined into one current survey

Many of the monitoring programs were initiated to address operational questions of the department. Such as, how much biomass can be harvested by fisheries? Today, we ask other questions about the state of our aquatic ecosystems. Fortunately, it turns out that the status of top predators captured in our multi-species surveys tells us a lot about the ecosystem. These surveys are also the main source of information for identifying species at risk and the boundaries of ocean management areas and marine protected areas. Thus, over time there is more and more interest in the results of our monitoring programs, yet paradoxically, no money from Species at Risk or the Oceans Action Plan budgets has been set aside for this fundamental task.

As an aside, because of their short-term nature, discovery surveys are the result of excellent partnerships with universities and other agencies. One good example is the International Biological Program (IBP) during the 1970s. Other examples include GLOBEC (Global Oceans Ecosystems Dynamics), OPEN (Ocean Production Enhancement Network), SSIP (Scotian Shelf Ichthyoplankton Project). These programs have allowed snapshots to be taken of a wide range of Canada's aquatic habitat. Some thought should be given to repeating these snapshots and providing a comparison of the past with today's conditions. A re-sampling of sites investigated under IBP might be very compelling, particularly in the Arctic. A separate Memorandum to Cabinet or NSERC strategic grant might be the appropriate means for procuring funds.

That said, it is important to note that academia may not be ideal partners for ventures in long-term monitoring. Academics are generally interested in short-term research, primarily for graduate theses. This type of work can greatly add to the value of a monitoring program but can not sustain it. Sustained, systematic long term ocean monitoring programs are normally conducted by government institutions. That said, there are other institutes, and government departments that are involved with ocean monitoring for long term and short term programs (see section 8). In Canada, examples such as the multi-year ArcticNet program for Arctic science, or the University of Victoria-led NEPTUNE (North-east Pacific Time-series Undersea Network Experiment) program showcase academic programs with links to DFO ocean monitoring requirements.

The need for improved coordination between all agencies involved in ocean monitoring is not unique to Canada. The most advanced national plan is arguably the US Integrated Ocean Observing System (IOOS). IOOS has been identified as a high national priority and emphasized the importance of interagency cooperation for successful implementation. Successful implementation depends, to a great extent, on enabling connectivity between the research motivated by IOOS mission requirements and that of the ocean science community in general.

The IOOS is a coordinated national and international network of observations and data transmission, data management and communications (DMAC), and data analyses and modeling that systematically and efficiently acquires and disseminates data and information on past, present and future states of the oceans and U.S. coastal waters to the head of tide.

The IOOS is part of the U.S. Integrated Earth Observation System (IEOS), the U.S. contribution to the Global Ocean Observing System (GOOS), and a contribution to the Global Earth Observation System of Systems (GEOSS). Sixty countries, the European Commission and more than 40 international organizations are supporting the development of GEOSS that, over the next decade, will revolutionize the understanding of Earth and how it works. The GEOSS initiative will promote the development of a comprehensive, coordinated and sustainable Earth observations among governments and the international community to improve our ability to understand and address global environmental and economic challenges.

http://earthobservations.org/

The Canadian Group Earth Observations (CGEO) is part of Canada's contribution to the GEOSS initiative.

http://www.cgeo-gcot.gc.ca/

The federal Cabinet has approved many Canadian GEOSS initiatives in principle, and has recently announced funding for key Canadian climate GEOSS contributions. A Federal Earth Observation Strategy is being prepared to help plan and coordinate Canadian domestic and international actions in the context of the development of an international Global Earth Observation System of Systems (GEOSS). This draft has been prepared by a small Interdepartmental Task Team composed of representatives from the Canadian Space Agency, Environment Canada, Fisheries and Oceans, and Natural Resources Canada. This Federal Earth Observing Strategy defines a vision and long term outcomes for Earth observation in Canada and proposes a practical focus on ten socio-economic benefit areas of importance to Canadians (not in any order of priority):

- Socio-economic benefits for Canada;
- Reducing loss of life and property from natural and human-induced disasters;
- Understanding environment factors affecting human health and well-being;
- Improving management of energy resources;
- Understanding, assessing, predicting, mitigating and adapting to climate variability and change;
- Improving water resource management through better understanding of the water cycle;
- Improving weather information, forecasting, and warning;
- Improving the management of terrestrial, coastal, and marine ecosystems;
- Supporting sustainable agriculture and forestry, and combat land degradation;
- Understanding, monitoring, and conserving biodiversity; and,
- Monitoring and protecting the fragile Northern environment.

DFO monitoring programs will form a key deliverable to Canada's commitment to the development of GEOSS, as they directly support virtually all of these socio-economic areas.

GOOS, an initiative of the Intergovernmental Oceanographic Commission, is being designed and implemented to meet the requirements of international agreements and conventions. Agreements calling for actions that address the seven societal goals of the IOOS include the Safety of Life at Sea Convention, the United Nations (U.N.) Framework Convention on Climate Change, the Convention on Biological Diversity, and the U.N. Conference on Environment and Development's Global Programme of Action on Sustainable Development. Development of the IOOS influences, and is guided by, the design and implementation of GOOS.
http://www.ocean.us/documents/docs/11.04.05_IOOS%20Development%20Plan_119.pdf

7.1 Atlantic

Relative to other parts of the country, monitoring of aquatic organisms and environment has been more comprehensive in the Atlantic zone. There are a number of reasons, ranging from the vision and leadership of many scientists of the Fisheries Research Board of Canada, monitoring requirements associated with the formation of the International Commission for the Northwest Atlantic Fisheries (ICNAF) and the expansion of DFO Science capacity that accompanied the introduction of the 200 mile limit in 1977.

Monitoring dates back to the start of the 20th century with the establishment of the St. Andrews Biological Station. In May 1915, the Canadian Fisheries Expedition, the first oceanographic study of the Gulf of St. Lawrence and the Scotian Shelf, began under the leadership of Johan Hjort, a Norwegian fisheries scientist invited to Canada to investigate herring stocks and their environment. In the mid-1920's, the Biological Board of Canada (later to be known as the Fisheries Research Board of Canada) became directly involved in fisheries research and monitoring of aquatic ecosystems. At first, besides fish catch statistics, long-term monitoring was limited to a few parameters such as water temperature. The first surveys in the Atlantic coast were primarily focused on specific species (herring, Atlantic salmon, groundfish). Some surveys were primarily exploratory to identify new resources to be exploited but others aimed to obtain basic biological information and gain a basic understanding of the make-up of aquatic ecosystems.

With the formation of the International Commission for Northwest Atlantic Fisheries (ICNAF) in 1949, there was a need to expand monitoring activities. In particular systematic sampling of fishery catches started about that time. Systematic monitoring of hydrographic conditions began in the 1950s as did the monitoring of counts of Atlantic salmon in many rivers in the Atlantic provinces. As well, it became apparent that surveys of commercial fish species would be important to address issues raised by ICNAF (and later by its successor NAFO) in terms of the management of fish stocks in Atlantic Canada. Systematic monitoring of Atlantic coast demersal fish communities began in the early 1970s. The monitoring was the basis of advice for fisheries management provided by the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) after the extension of jurisdiction. It also became apparent that increased understanding could be gleaned if the monitoring of oceanographic and environmental parameters, which had been conducted mostly separately from surveys of aquatic fauna, would be conducted simultaneously. For the past two decades most of these surveys also include observations of invertebrate communities and physical, chemical and biological oceanographic characteristics. These surveys are currently conducted annually on almost all the major shelf regions of the Atlantic coast.

Progressively, a number of other monitoring programs have been put in place to monitor the abundance of specific species (e.g. snow crab, herring), study climate change, and several other issues. In 1998, AZMP was created to coordinate and ensure that the minimum requirement to adequately detect and measure inter-annual variability of ocean conditions in the Canadian Atlantic. It involves the multidisciplinary monitoring of biological (plankton abundance and/or biomasses), chemical (nutrients) and physical (temperature, salinity) variables of the marine environment. It was built largely on existing field and monitoring programs, and is linked with other monitoring programs (e.g. fish surveys, remote sensing). As such, it is a good example of how a monitoring system can be structured.

7.2 Arctic

With the disbanding of the Arctic Biological Station on March 31, 1992, there has been a large decline in Arctic monitoring. This station was responsible for monitoring programs for marine mammals and physical characteristics of marine and fresh waters.

7.3 Fresh water

Historically, Canada’s largest aquatic monitoring program was in fresh water. Not a surprise, considering that our country has 15% of the world’s rivers and lakes. Long term studies have been conducted throughout the Great Lakes (e.g., Vollenweider, Langford) and at lakes in other parts of the country (e.g, Char, Okanagan, Keller, Opeongo, Winnipeg and more recently Experimental Lakes Area, ELA). The status of records for some of these early studies is uncertain. Since the establishment of the Canada Centre for Inland Waters in 1970, monitoring in the Great Lakes has been reasonably thorough but inconsistent both spatially and temporally due to the lack of consistent funding. In the past two decades, there has been a rapid decline in this kind of monitoring. EC leads most freshwater water-quality monitoring (e.g., hydrology, nutrients, contaminants in water), but not monitoring of biota. Parks Canada conducts surveys in Canada’s 41 National Parks and two National Marine Conservation Areas. DFO’s focus is mainly counting of lamprey, salmon and other diadromous fish at selected sites across the country. Other than the Great Lakes and ELA, there is little systematic sampling in other parts of freshwater Canada.

7.4 Pacific

The Pacific Region is characterized by a relatively narrow continental shelf with extensive semi-enclosed (Hecate Strait, Queen Charlotte Sound) and enclosed (Strait of Georgia) basins. The enclosed basins are relatively deep (up to 400m) and they are linked to a complex network of small island archipelagos and long, deep fiords which reach deep into the interior of the province.

The near-shore and continental shelf environments are influenced strongly by both terrestrial influences (mainly high freshwater runoff) and open ocean influences, through the deep passages. The continental shelf and offshore regions are part of both the California Current System (Vancouver

Island and South) and the Alaska Current System (Queen Charlotte Sound and north). Both of these features have their own unique ecosystems. The Alaska Gyre is cold, rich in nutrients and an important feeding ground for salmon, cod and herring. The California Current is warmer, poor in nutrients and dominated by hake, sardine and anchovy. These features are greatly influenced by El Nino and the Pacific Decadal Oscillation, resulting in large-scale changes in productivity over a thousand kilometers up and down the coast. Most years from 1977 to1999 were warm and less productive than other years, with significant negative consequences for returns of salmon in the south.

There is a fairly complete literature that describes the impact of ocean climate variation on fish stocks throughout the North Pacific, but the detailed cause and effect relationships are not always obvious. For salmon, the challenge of predicting variations in marine survival due to ocean conditions is further complicated by the large variation in freshwater growth and survival.

Despite the high variability of the ocean environment, there are few monitoring programs that are used to describe the state of sub-surface ocean conditions along the Canadian Pacific coast. The longest program is the Ocean Station Papa Line. It consists of vertical profiles of the water column at about twenty locations along a transect from Vancouver Island to a point 1000 kilometers west, in water nearly four kilometers deep, the average depth of the ocean. Each profile consists of observations by depth of nutrient, temperature, oxygen, primary productivity and secondary productivity. This work has been conducted off and on, up to several times a year, for about 50 years. Any analysis of the marine environmental conditions on the west coast of Canada starts with this monitoring information. This is also the premiere open-ocean time series anywhere in the world's oceans. Data from the Station P/Line P program have been used globally to test and constrain numerical models of ocean circulation, biological production, carbon cycling and climate change. This is a significant contribution by Canada to international/global monitoring efforts.

This predominantly deep-ocean time series has been augmented by the La Perouse Project. This project combines fisheries and oceanographic monitoring on the continental shelf off Vancouver Island in a highly productive fisheries area. The project has run at varying levels of intensity since 1985 and includes profiles of water properties (more or less seasonal), long records from moored current meters, plankton production (biomass and composition) and fisheries production (various species including Pacific hake, herring and sardines); it was started as a long-term research project, but has never quite matured into a recognized and supported permanent monitoring program like AZMP. It does not attempt to provide coast-wide coverage.

Additional monitoring of the physical marine environment is provided through:

a) BC Lighthouse Program – daily measurements of sea surface temperature and salinity from manned coastal lighthouse. Time series extend from 1921 to present for some stations.
b) Permanent water level network. – measurement of tidal height from coastal stations. Time series extend from 1905 to present for some stations.
c) EC/DFO meteorological buoy network – this array of moored buoys was established in 1988 improve detection of intense low pressure areas and improve safety for fishers. These buoys are primarily meteorological platforms, but include measurements of sea surface temperature and wave height.

Fishing surveys targeting groundfish species on the B.C. coast have been widely used in the past. Approximately 680 groundfish surveys have been undertaken by DFO in the Pacific region over the last 60 years. Early surveys were largely exploratory. Survey work in the1940s and 1950s, focused on the discovery of new fishing grounds. In the late 1960s surveys were initiated to facilitate the assessment of stock status. During the 1970s, 1980s and 1990s a great deal of effort was focused on evaluating the effects of various commercial fisheries on the groundfish resource. During the latter period effort was focused exclusively on single species abundance indexing and funding was provided by the federal government.

The groundfish trawl fishery on the Pacific coast is a multi-species fishery with over 200 species caught. To date only some 20 species stocks have been regularly assessed. To meet the demands of a more complex society and increase efficiency where resources were limited, a new approach was necessary. In 2003 scientists at the Pacific Biological Station developed a coast-wide plan for multi-species surveys that encompassed every area on the Pacific coast with each area receiving survey coverage every two years. Funding for this work is provided by the commercial fishing industry and stakeholders helped design the surveys and also participate in them. These multi-species surveys meet the more complex requirements of fishery managers, address recommendations of the recent Stock Assessment Review, provide support for legislation contained in the *Species at Risk Act* and address the need for Ecosystem Management.

Since the late 1920s, there have been organized efforts to assess the amount of herring eggs deposited throughout the British Columbia coast as an indicator of stock abundance. The surveys were initially conducted by Fishery Officers who monitored the spawning events on foot at low tide or from skiffs using a grapple. They measured the total length of each egg bed along the shore and the average width perpendicular to shore. Prior to 1981, intensity of egg deposition was estimated subjectively on either a 1-5 or 1-9 scale for light to heavy depositions. Subsequently, intensity of egg deposition was recorded as the number of egg layers observed on each of several types of algal substrate. Beginning in 1987 an increasing proportion of the spawning beds have been surveyed using SCUBA techniques. SCUBA surveys rely on teams of divers collecting observations on herring egg deposition using a two-stage sampling design that is based on the visual assessment of egg layers on various algal substrates in 0.5 m2 quadrats assessed along transects set perpendicular to shore across egg beds every 350m along the length of the spawning event. The SCUBA surveys were conducted initially with DFO staff, primarily Science and Fishery Officers until the early 1990s. As resources dwindled, the responsibility for spawn surveys was transferred to the herring industry and they have been conducted through the test fishing program funded by the Herring Conservation and Research Society.

In addition to the spawn surveys, biological samples of herring are collected for age, length, weight, and sexual maturity throughout the British Columbia coast. The monitoring of these biological characteristics extends back to the 1930s in some areas and has been consistently collected since 1951 throughout the major fishing areas. A rigorous sampling program was instituted in the early 1970s at the beginning of the modern roe herring fishery to collect standardized biological data on roe maturity as part of a test fishing program. The test fishing program is funded through an allocation of herring to the Herring Conservation and Research Society. A similar program exists to monitor the total catch from the fisheries. It is based on a validated landing program funded by the herring industry through charges to individual fishers.

Pink and sidestripe shrimp stocks along the coast of British Columbia have been monitored since 1973. The first intensive science based monitoring program for shrimp was initiated in 1973 off the West Coast of Vancouver Island. This program is ongoing and provides a time series of information from 1973 to present (2005). This particular monitoring program was expanded in 1996 to also include Pacific Fisheries Management Areas (PFMA) 121 and 123 and expanded further in 1998 to include Queen Charlotte Sound. Although this program was originally designed for the various shrimp species all organisms encountered (about 150 species) are identified to species and quantified. As a result, this survey has proved to be a very valuable multi species monitoring program for invertebrate, groundfish, and pelagic fish stocks.

The monitoring of several shrimp species inhabiting the near shore waters along the coast of British Columbia was initiated in 1998. This program is survey based and has established index areas in PFMAs 28, 29, 18, 19, 14, 12, and 4. These surveys are multi-species to the extent that fish sampled and quantified are restricted to small individuals due to the necessity to employ excluder gear. These surveys are carried out in collaboration with industry with funding for this program from the commercial shrimp trawlers. Under a Joint Partnership Agreement with the Pacific Coast Shrimpers Cooperative, DFO provides the vessel time and industry provides funding to the Department for data collection, data management, data analysis and reporting.

The monitoring of prawn stocks along the coast of British Columbia is divided up into 3 general programs. The one program that utilizes a Department vessel is an intensive monitoring program in Howe Sound (the coast wide index site) that provides an index of all trap-caught species which includes many invertebrate species, several rockfish species and other groundfish. For prawns this program provides estimates of key biological parameters (e.g. natural morality, recruitment, spawner abundance) that are used in the development and refinement of the spawner-escapement index for prawns. This program is trap-based, conducted in-house, and involves two surveys per year using a department research vessel and has been ongoing since 1985. The second program is an in-season sampling program funded by the commercial prawn industry that monitors the prawn escapement index during the commercial fishery. This program has been ongoing since the early 1990's and utilizes fishery independent at-sea-monitors to sample the commercial catch. The third program was implemented in 2001 and monitors prawn stocks in high use recreational fishing areas by having a commercial vessel with observer fish the area of concern.

Pacific deepwater assessment surveys were begun in 1999. The focus of initial surveys was to assess stocks of deepwater Tanner crab (*Chionoecetes tanneri*) off British Columbia, while collecting data on other species encountered. The associated fauna was richer than expected and relatively undocumented because surveys and commercial fisheries at these depths were rare. Focus of the surveys shifted to gathering baseline data for all species encountered, particularly as industry interest in Tanner crab fishery development decreased.

The coast was divided into four areas: Southwestern Coast of Vancouver Island (SWVI), Northwestern Coast of Vancouver Island (NWVI), Queen Charlotte Sound (QCS) and West Coast Queen Charlotte Islands (WCQCI). Each zone was to be assessed in rotation, thus the entire coast would be completed in a four-year cycle. To date, NWCI has been sampled twice (1999, 2003), QCS once (2000), SWVI twice (2001, 2005) and WCQCI once (with partial coverage in 2002 and 2004 due to vessel mechanical problems).

At least 190 species of fish and over 400 invertebrate species have been documented in these surveys, many for the first time from British Columbia waters. Twenty-four species of fish have been reported for the first time from Canadian Pacific waters, as have three crabs, three cephalopods, two shrimp and one bivalve mollusc. Additionally, three new species of black coral and one new octocoral were collected and descriptions have just been published.

Marine mammal surveys in the Pacific region include a triennial sea lion survey that is conducted jointly with the US; an annual killer whale survey; and, an annual sea otter survey.

7.5 Pacific salmon

Almost one fifth of Canada's monitoring program is spent on the five species of Pacific salmon (no DFO funding for steelhead), and has provided a long list of data on catches and numbers of salmon reproducing (spawning escapement) spanning many decades. The data though have varied through time as demands have changed. Very few 'stocks' of salmon have a time series of data necessary to study productivity of salmon, but many have a long history of consistent annual enumeration surveys. The remainder of known spawning streams is monitored sporadically and qualitatively to examine habitat conditions and distribution of salmon.

Historically, monitoring focused on commercial-catch accounting with wide-spread, low-intensity visual surveys to observe trends in spawning escapements. Sampling may have been adequate for those times since the fisheries were intensive and accounted for a significant portion of the total salmon production. Trends in catch were assumed to be representative of changes in abundance. After development of the stock-recruitment management paradigm and the development of stock identification tools using scale pattern analysis (circa 1955), a limited number of populations were monitored quantitatively (e.g., Babine Lake sockeye by the Fisheries Research Board of Canada, Fraser River sockeye under the International Pacific Salmon Fisheries Commission). Monitoring focused on commercially important stocks. However, many other stocks were less carefully monitored, resulting in a loss of diversity in smaller populations. Following the increase in world attention on biodiversity (late 1980s) and efforts to develop the Wild Salmon Policy, monitoring effort was re-directed to examine diversity of salmon populations, focus sampling on populations of conservation concern, and to maintain 'indicator' stocks (i.e., populations intensively sampled to estimate exploitation and marine survival rates in order to explain changes in salmon production over time).

Today, the WSP recognizes that salmon have a complex hierarchical population structure extending from the species all the way down to groups of salmon at individual spawning sites, as indicated in the figure below. Their precise homing to natal streams and their death after spawning restrict gene flow among fish at different spawning locations. However, since some salmon stray, genetic exchange also occurs among fish from different spawning locations. Each spatial grouping of Pacific salmon consists of a hierarchy organized on a geographic basis and consisting of watersheds with multiple rivers and many spawning areas.

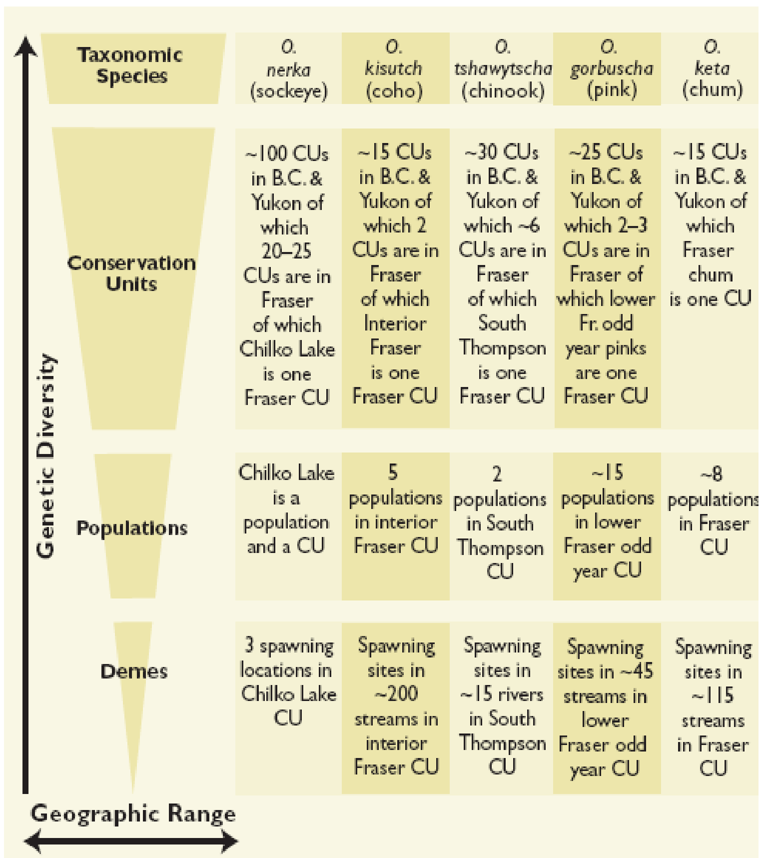

Figure 6. Schematic representation of genetic diversity and Conservation Unit structure, from Wild Salmon Policy.

For wild salmon in the BC and Yukon, however, quantitative assessment is a complex and potentially costly task, involving numerous data sources and hundreds of populations. Consequently, the Department has utilized three levels of annual monitoring programs in the assessment of Pacific salmon:

i) **Indicator systems:** Comprehensive programs involving quantitative information on the spawning adults, juveniles produced, mature progeny produced (reported in the catch and spawning numbers) from the specific system. These programs are the most information rich and expensive but provide critical information for management such as productivity and sustainable rates of exploitation, survival rates for major life history phases (e.g., freshwater and marine survival), and exploitation patterns and rates in fisheries.

ii) **Intensive monitoring**: Annual surveys of the numbers of salmon in specific subsets of streams or habitats within a geographic area. These surveys involve quantitative designs that can be replicated annually to provide consistent indices of spawners between years. The accuracy and precision of the estimates will vary with methods and habitats but the essential component is that there is a high degree of confidence that inter-annual trends are accurately assessed. For example, methods may involve in-river test fisheries, counting weirs, mark-recapture programs, area-under-the-curve estimators, and surveys of juvenile production in streams and lakes.

iii) **Extensive monitoring:** Surveys that are generally the least expensive but enable the broadest coverage of streams or other habitats within a geographic area. These surveys are useful for examining salmon distribution, consistency of patterns throughout the region, and checks on habitat changes. They are usually visually-based, may be repeated within a year, and may include randomly selected samples of the streams or habitats in a large geographic area. Examples of these surveys are over-flights, stream walks or floats, and could involve only portions of a stream instead of the entire system.

For each Conservation Unit (CU), a statistically-based and cost effective monitoring plan will be designed and will build on existing programs and local partnerships (e.g., First Nations agreements, local Streamkeeper or enhancement groups). Monitoring programs must assess the annual abundance of the CU and the distribution of spawners. The assessment procedures applied will vary between CUs but monitoring plans for each CU will be documented and information reported annually. The benchmarks specified for a CU must be stated in units consistent with the monitoring program for that CU in order that the annual status of the CU can be assessed. A core program (i.e., an agreed minimum monitoring plan) will be established by the Department and partners and funded annually to maintain the long-term information fundamental to management of local salmon resources. Each monitoring plan will be peer reviewed to ensure application of appropriate designs and methods, best use of available resources for monitoring, and to ensure that information management systems have been developed. A key objective of these monitoring programs will be to make certain that data collected are utilized and timely for the provision of advice.

Habitat monitoring is intended to identify changes in habitat condition over time. This monitoring will be integrated with salmon assessments and ecosystem evaluations[1]. The intent will be to better understand the relationship between changes in habitat condition and changes in salmon production and distribution within the CU. Monitoring will also be used to assess the effectiveness of regulatory decisions and rehabilitation measures.

8. Shared Responsibilities

Two-thirds of the responsibility for aquatic monitoring is currently held by DFO Science. Other partners include a full range of government and private agencies.

1. Partnerships are generally asymmetrical with the main responsibility resting with DFO. There are no MOUs except between DFO and EC for the joint support of the offshore meteorological buoy system in Pacific.
2. In general, EC is strong in fresh water, but they do not monitor biota, except herring gull eggs (Canadian Wildlife Service). EC is weak in the marine environment with the exception of monitoring with respect to permits for ocean dumping and monitoring of oiled sea birds and

[1] The WSP requires that an approach to ecosystem monitoring be developed. Within two years, an ecosystem monitoring and assessment approach will be integrated with ongoing assessments and reporting on the status of wild salmon.

bacterial contamination: It is noteworthy that the latter is the responsibility of provinces in fresh water.

3. DFO is responsible for monitoring nutrients in all marine areas.
4. CFIA is responsible for collecting and analyzing shellfish samples for marine biotoxins. DFO's residual role (with the creation of CFIA) is unclear.
5. In Atlantic and Arctic, NRCan shares the monitoring of sediments with DFO. In Pacific, DFO is the sole agency with this responsibility. NRCan has a weak sediment program on the Pacific Coast.
6. There is considerable confusion with regard to the monitoring of contaminants. EC monitors point sources. DFO monitored contaminants in Great Lakes fishes for the past 29 yrs, but the transfer of this activity to EC is currently being discussed. In Pacific, DFO monitors organisms with regard to population health, e.g. killer whales and contaminated fisheries (e.g. closures due to dioxins/furans from pulp mills). In Québec, a private research agency conducts the monitoring of contaminants in marine mammals. In Gulf, DFO monitors contaminated fisheries, e.g. cadmium. In the Arctic, DFO has been monitoring contaminants in freshwater and marine fishes, and marine mammals. Future emphasis will be focused on health of marine mammals, and in support of oceans action plan initiatives.
7. There is a need for Canada to integrate the monitoring work of the different federal and provincial agencies as is done in Korea and France
8. In the Arctic, co-management partners in monitoring are included under land-claims agreements.

9. Quality Assurance and Access to Information

Any monitoring program requires a structured approach to survey protocols, as well as data archiving and access. A comprehensive report on marine environmental monitoring in the United States concluded that most monitoring programs fail to provide the information needed to understand the condition of the marine environment or to assess the effects of human activity on it. (See http://www.nap.edu/books/0309041945/html/).

The Atlantic Zone Monitoring Program has well-described protocols and standards and provides a good example of a structured approach. The merit and utility of any monitoring programs that continue without clear protocols for data management need to be critically examined. This auditing exercise is within the purview of the Data Management Team.

Monitoring programs are only as good as the data that they generate, thus requiring a great emphasis on quality assurance and data distribution. This becomes especially important when considering partnering with outside collaborators without a strong scientific and data culture (i.e. fishers and community groups). A large number of monitoring activities fall into the category of short-term, issue-driven programs. This component is largely funded from temporary sources like ACRDP (Aquaculture Collaborative Research and Development Program) and FSCP (Fisheries Science Collaborative Program) and is becoming a concern in the context of monitoring, although these projects often collect invaluable information on the status of the environment, and appear to be growing. The quality of data can be variable, particularly when the projects are narrowly focused on immediate deliverables and insufficient attention is paid to the long-term monitoring aspects. The team was concerned by this category because long-term monitoring requires sustained funding. In general, aquatic monitoring is limited in Atlantic and Pacific and almost non-existent in the Arctic, northern Boreal Shield lakes and the pelagic component of all ecosystems.

We have other examples where insufficient attention to quality control renders an otherwise wonderful time series useless. One example is the long series of weekly temperature and salinity profiles from the Naval test range in the Strait of Georgia, which is heavily compromised by low-quality and erroneous salinity measurements up to the mid 1980s. Of course, we are all aware of cases where insufficient attention to data management has resulted in losses of historical data. The closure of the

Arctic Biological Station at St. Anne-de-Bellevue is one striking example, where there was a complete loss of original data. It was felt that all dedicated monitoring programs should be protected and careful analysis should be conducted before discontinuing any of them.

Some "monitoring" results can be obtained by "piecing together" data from disparate sources to assemble "monitoring time series". An example is the work by Dario Stucchi on deep water changes in BC Inlets (http://www-sci.pac.dfo-mpo.gc.ca/osap/projects/bcinlets/all_inlets_e.htm). This is clearly an attractive option, but this study revealed some caveats. The analysis relied very heavily in its early days on data collected by the Institute of Oceanography at University of British Columbia (IOUBC). The Director of IOUBC at the time placed a very high level of importance on both quality control and data management (published technical reports). We do not see this emphasis in many, if any, academic programs today. The success of this project relied heavily on DFO's large investment in "after the fact" data management by both Marine Environmental Data Service (MEDS) and staff at Institute of Ocean Sciences (IOS) in the form of data entry, data file translation, quality control and reduction of duplicates.

The above example shows the need to be able to put together data from all sources pertaining to an ecosystem. Currently this task can be daunting, and improved accessibility would greatly enhance its value while providing greater visibility for DFO sciences. It was felt that access would be improved if all monitoring activities were identified either on the DFO Canadian Science Advisory Secretariat (CSAS) web site by providing an entry point to all aspects of scientific advice or through data portals like the Observatoire Saint-Laurent (OSL) or the Meteorological Service of Canada. Although this is strictly under the purview of the Data Management team, the group felt it was an important step in the rationalization and optimization of the monitoring program.

State-of-ecosystem reports provide an excellent venue to evaluate the accessibility and pertinence of monitoring programs and to identify any gaps. These reports are provided every five years for the Great Lakes and it was felt that a similar schedule should be developed for ecosystems across the country. The recent Ecoregions report could be a guide to identify the main marine ecosystems. Nevertheless, it was felt that where the boundaries in this report disagreed with well-established management boundaries, the latter should be used. It was also noted that LOMA boundaries are yet to be determined and approved at the national level for the Arctic.

10. Monitoring Needs and New Priorities

10.1 Arctic

Many of our northern areas are not adequately monitored. These include all parts of the Arctic, northern Labrador, northern boreal lakes and the northern coast of British Columbia. We need to specify what level of monitoring is required here and what DFO's responsibilities are. For example, are monitoring programs a federal responsibility under northern land claim agreements (e.g *Nunavut land claims – Article 20*)?

CCG vessels make regular trips to the Arctic , departing from and returning to home ports in the Pacific and the Atlantic zones and have done so for 30 years, but up to now do not collect any basic oceanographic information. It was felt that a very modest investment and some inter-sectoral communications would help the CCG to deliver on all of the strategic outcomes of the department as currently attempted under the Études des mers intérieures du Canada (MERICA) project focused on Hudson's Bay.

ArcticNet will provide opportunities for DFO scientists who are affiliated with universities to participate. However, this does not mean that all scientists will participate.

International Polar Year (IPY) will be calling for proposals to spend $150M over two years on Arctic science (http://www.ipy.org/development/eoi/proposal-details.php?id=90). This money could be wisely invested in either a) pilot projects that in turn could test the required frequency and best locations for long-term monitoring programs; or b) complete a census of Arctic aquatic fauna and flora to be compared to previous studies that were conducted 30-40 years ago.

10.2 Monitoring to support the Species at Risk Act (SARA)

The government's process to support the listing and protection of species at risk as prescribed within the Act, requires information on the distribution, abundance, habitat requirements, and threats to assess the status of a candidate species through the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). It also requires the biological information, to protect, plan for recovery, and monitor the recovery of species that are listed. Currently, there are 145 aquatic species that are listed as extinct, extirpated, endangered, threatened or of special concern.

For marine species within DFO's jurisdiction, the long time series provided through our trawl survey data have been crucial to evaluate changes in abundance for some species assessed through COSEWIC. In many instances this is the only source of information for this process. Data from these surveys represent a unique and sufficiently long time series that has been gathered in a scientifically rigorous manner. This is essential in order to have objective evaluations of distribution, habitat requirements, and decline in population abundance. For some species, time series data available from commercial or recreational fisheries have been important sources of information for COSEWIC.

For marine mammal and freshwater species, the information needs are the same, although monitoring methodology and platforms are different. In addition, the scope of taxa assessed by COSEWIC is expected to widen in the future and will eventually include more marine invertebrates.

The need for this information is only anticipated to grow and remain a constant as new species are raised as priorities for assessment, as listed species are reassessed, and the monitoring of harm and recovery become required by federal law. Unfortunately, the current program to monitor commercial species abundance is not best designed to gather this knowledge for the 'rare', less well understood species that become the majority of concern. It is imperative that some of the SARA funding be directed towards monitoring of marine species, in particular towards partial funding of multi-species trawl surveys and new surveys designed to cover poorly sampled areas such as the near-shore coastal zone. In addition, further consideration must be given to monitoring programs to support the gathering of data for other aquatic species under DFO's jurisdiction. This will be difficult for freshwater species until DFO develops a clear approach to dealing with freshwater issues with the Provinces. It must be recognized that for Pacific salmon, the unit that can be listed under SARA is a population, not a traditional taxonomic species, which can result in onerous monitoring requirements.

Monitoring for rare species may require different survey designs and sampling strategies than our existing trawl surveys, which are designed to measure biomass of relatively abundant species for commercial harvest. Substantial effort is required in identification and quality control and assurance of rare species/populations, including preparation of taxonomic keys/guides, maintenance of reference collections, independent verification by outside experts and provision of genetic descriptions.

Certain aspects, such as monitoring of by-catch and observer programs could be considered as an additional cost to be completely born by the private sector, as it already is by some fishing sectors. By-catch monitoring is only one example of assessing ecosystem impacts of activities that DFO regulates, including impact to the target resource, non-target species, habitat, and other fisheries and resource uses.

10.3 Monitoring to support the Oceans Act

Science has been asked to identify Ecologically and Biologically Sensitive Areas (EBSAs) and Ecosystem Objectives (EOs) within the following large ocean management areas (LOMAs). Each LOMA was evaluated for its ability to provide information on performance indicators of ecosystem-based management (Table 4). While LOMAs require monitoring for management decision-making, MPAs require monitoring for better understanding and evaluation of their performance to meet given objectives.

a) Pacific (Pacific North Coast Integrated Management Area - PNCIMA LOMA)

There is limited physical oceanographic information, almost no information on nutrients, very limited information on primary and secondary production, benthic communities and habitat, and no information on background levels of contaminants such as oil in this area. Fisheries observer data are good but the fishery is very localized. Hecate Strait has a complex internal structure, shelves and a deep canyon, such that averages over the area are of limited value. There is some multi-species trawl information. There are sensitive habitats (sponges and corals) that require mapping. The Royal Society of Canada convened an expert panel to review the science gaps associated with potential oil and gas exploration in this area. The Panel produced a detailed report of the gaps. Most of the identified gaps are within the jurisdiction of DFO (http://www.rsc.ca//index.php?lang_id=1&page_id=115#report).

Endeavour Ridge MPA is Canada's first designated MPA. The research and monitoring activity at this MPA is dominated by the US NSF-funded RIDGE2000 project and there is no DFO money allocated for sustained observations. The DFO monitoring component (funded through Collaborative Agreement with US investigators) will end in 2005. Some components may be replaced by The North-East Pacific Time-Series Undersea Networked Experiments (NEPTUNE) installations in 2007/8. There is no regular monitoring activity in the second, **Bowie MPA,** except for the sablefish trap fishery. .

b) Arctic (Beaufort LOMA)

This area is at the discovery-level of information gathering. There is some basic knowledge of nutrients and physics but very little long-term monitoring of any kind. Because of cloud cover, there is little information on chlorophyll that is available from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). The fishery information is weak relative to southern coastal areas. There is some information on the fish, benthos and zooplankton biomass and diversity near the area of interest for petroleum extraction. The single MPA is **Tarium Niryutait.**
This area is focussed on the health, abundance and harvest of beluga.

c) Atlantic (Gulf of St. Lawrence, Eastern Scotian Shelf, Placentia Bay-Grand Banks LOMAs)

For all three of the Atlantic LOMAs there is good information on fisheries and areas of depth >20 meters. Most gaps are in the near-shore areas, particularly the small benthos.
Sensitive habitats are generally near-shore and not well monitored. Monitoring of other human activities, such as shoreline encroachment, has not been organized. In general seascapes occur at finer scale than the available data.

There are seven MPAs in the Atlantic. None of them was located at sites with established long-term monitoring and none has identified costs for this activity. Yet most of them have a resource or feature that requires monitoring. For example the **St. Lawrence Estuary** is focussed on cetaceans. **Basin Head** is focussed on Irish moss. **Gilbert's Bay** is focussed on a unique cod population. **Eastport** is focussed on lobster. The **Gully** is focussed on bottlenose whales and seabirds. **Manicouagan** and **Musquash** are focused on protecting unique habitats.
Long-established monitoring sites should be given priority for any future MPAs.

10.4 Monitoring to protect fish habitat

The Oceans and Habitat Sector has developed a national computer system to track the regulatory activities of the Habitat Management Directorate [Program Activity Tracking for Habitat, (PATH)]. This includes tracking information on individual development proposals referred to DFO for review for impact to fish habitat under provisions of the *Fisheries Act*.

Outside of tracking specific referrals, there is very little systematic monitoring of Canada's coastal and littoral zones, which are key habitats for many aquatic species. An exception is the monitoring of herring spawn habitat on the Pacific coast. Without some leadership, we will be unable to track any small-scale incremental losses of littoral habitat that are believed to be occurring. In general, academics and graduate students are in a good position to monitor these habitats because they do not require large vessels in order to study them, although monitoring has not been a traditional activity of academia. An inventory needs to be developed for field study sites. Information collected at these sites needs to be archived and coordinated among researchers. In addition, new studies need to be implemented in some critical habitats. DFO could play an important role resolving these needs, particularly with regard to data management. A re-kindled subvention program might be a good source of funding for this type of work. The team notes that it is highly optimistic to think that academia would pick up this work on a sustained basis.

Another gap is the ability to assess cumulative impacts. This type of work requires detailed study in specific locations, such as Experimental Lakes Area. Equivalent long-term study sites need to be acquired in the marine environment. Again, the academic community may be able to assist.

10.5 Monitoring secondary productivity

A serious weakness within the Canadian aquatic monitoring program is the inability to understand changes in secondary productivity and food webs in different regions of the country. There have been shifts in species composition and abundance of copepods on the Scotian Shelf. But we do not know if comparable changes have also occurred in the Southern Gulf, the Great Lakes and the Arctic. There has also been a decline in euphausids (krill) in some marine regions. We are unable to compare productivity among these regions. The La Perouse program does allow detection of shifts and composition for the southern BC continental shelf (California Current system), but there is no such time series for northern BC waters (Alaska Current System) or inshore waters.

One standardized method for addressing these gaps would be surveys with continuous plankton recorders (CPR). The cost to establish annual surveys in the eastern and western Arctic and monthly surveys in the ice-free Great Lakes and Gulf of St. Lawrence would be about 150K per year. The detailed costs are provided in Table 5 to give some idea of the scale of investment required.

The monitoring team was supportive of the principle to invest in gathering this type of information but was leery of purchasing a technology that is nearly a century old. The team felt that the money should be directed towards developing and implementing acoustic, optical or automated devices to measure plankton. The team also requested a review of the CPR line on the east coast and how it compares to results from the AZMP, with particular attention towards an analysis of inter-annual variability.

10.6 Monitoring of aquatic invasive species

Better systematic monitoring of the near-shore coastal zones would help to describe the movement and distribution of invasive species. The Arctic is of particular concern because of the potential for increased shipping and the likelihood of introducing alien species. Invasive species tend to be outside the purview of most monitoring programs. Invasive organisms tend to be small and are not caught by trawls and some of this monitoring may be done using CPR surveys (see above). Programs like AZMP could be expanded to increase sampling in near-shore areas. As stated above, the academic community may also be able to assist by providing information from research sites. This monitoring requires taxonomic skills and precision, which are not always available. In addition, community and watershed groups are embarking on systematic surveys of their waters. This information needs to be collated and organized. Better coordination and communication would be helpful.

We need to carefully review if the existing surveys (designed primarily to estimate biomass of abundant species for assessing harvest potential) are appropriate for detection/tracking of rare species. We also need to review whether we have the required taxonomic expertise. All of these issues are currently being reviewed and addressed in the newly-established Aquatic Invasive Species Program (Environment and Biodiversity Science).

10.7 Monitoring of aquatic animal health

The new National Aquatic Animal Health Program (NAAHP) requires us to identify marine and freshwater zones with similar disease characteristics. Some of this information can be derived by sampling organisms via epidemiologically-based surveys. The funds are available to initiate such a program. This program is tightly focused on a specific set of listed, infectious diseases of aquatic animals that impact international trade in seafood products or are expected to cause harm if inadvertently introduced or moved within Canada. This is not a comprehensive survey of the prevalence of disease in marine and freshwater organisms.

10.8 Monitoring ecosystem health

Monitoring of contaminants in water, sediment and biota is a major concern of most Canadians. There needs to be a rationalization of work conducted by DFO, EC, NRCan and Health Canada to ensure that these concerns are met as outlined in the Health of the Oceans portion of Canada’s Oceans Action Plan. The capabilities/capacity/expertise of other government departments to carry out these activities in aquatic and marine environments is highly variable. For example, Environment Canada has significant capacity and expertise in fresh water systems, but little in marine environments.

Monitoring of harmful algal blooms is an activity that requires coordination with Canadian Food Inspection Agency (CFIA).

Monitoring of nearshore embayments in many coastal areas is inadequate. Areas like the lower Great Lakes, Strait of Georgia and Northumberland Strait have many conflicting user groups and require information for integrated management. Eutrophication and coastal development are important issues to manage in these areas and are priorities for the National Program of Action.

Other components of the ecosystem that are not well sampled include macrobenthos, small pelagic biota (larval and adult), non-endangered marine mammals and large pelagic biota (sharks and turtles).

10.9 Pacific Salmon

The future monitoring for Pacific salmon faces at least three significant challenges: implementation of the Wild Salmon Policy, cost efficiency needs, and more effective management of information.

a) Wild Salmon Policy: All populations of wild Pacific salmon will be accounted for within Conservation Units (CUs, spatial aggregations of populations). Within each Unit an assessment framework will be determined and two reference points will be defined (defined within the WSP) to assess status. The policy also requires the development of habitat and ecosystem indicators and a monitoring program. The assessment frameworks will be developed in a risk management context that will need to balance (a) the necessity for ‘indicator’ stocks (mechanistic programs to explain trends in salmon abundance and for research), (b) the commitment to more extensively monitor the diversity of salmon populations over time (i.e., to meet the public expectation of care for localized salmon populations, and (c) monitoring of specific SARA listed species (i.e., assessment of recovery, etc.). The latter is currently limited to Interior Fraser River coho salmon but increasing requirements to assess freshwater species assessed by COSEWIC will significantly increase the need for monitoring of those species that are currently unfunded. The information collected annually will be assessed against the impacts of human activities on CUs on the conservation and use of wild Pacific salmons.

b) Increased cost efficiency: There will undoubtedly be continued pressures to control expenditures while effectively monitoring Pacific salmon and their habitats. Three Regional activities are currently working towards this goal; (a) definition of a 'core' assessment program (i.e., the critical information needs for the management of Pacific salmon), (b) establishment of formal partnership agreements for the delivery of local assessment programs, and (c) the assessment of new technologies for assessing salmon escapements (increased use of electronic sampling tools to reduce the costs of field labour in remote locations). While each of these will contribute to efficiencies, they each carry risks that will need to be managed. For example, a core program is likely to be perceived as a minimal DFO commitment to local populations, use of partnerships increases the reliance of DFO on non-government agencies with varying commitments to long-term data collection, and electronic tools require funding for evaluation and verification. While these tasks have begun, the Pacific Region anticipates 5-10 years of implementation and testing.

c) Management of information systems: The design and implementation of new or expanded information management systems will be required as more information is collected and tasks expand (e.g., habitat and ecosystem indicators, GIS related data systems, etc.). However, the major task will be determining how to provide timely access to information that is now collected by DFO and partners, including extensive work required to integrate data systems between the provincial and federal governments. Information systems for salmon data are under-funded and poorly integrated with the provincial systems.

DFO staff involved with Pacific salmon assessment and information systems are seriously concerned that even with improved cost efficiencies, expectations under the WSP, SARA and annual fishery-management plans, will continue to exceed the regional ability to deliver without additional staff and resources directed to these tasks.

11. Areas for Some Rationalization or Improvement

Monitoring is clearly a regional activity. Regional decisions set the priorities for monitoring. Some monitoring is undertaken to meet international obligations but otherwise, there is no responsibility for science monitoring at headquarters. There are obvious benefits to having national standards for this important activity, a responsibility that would be best led by headquarters. Long-term data on state and health of aquatic ecosystems are required for effective decision-making and management. No other agency is committed to acquiring and maintaining this information.

The main sources of funding for the above-outlined new needs could be found by realigning several lower priority categories. No decisions have been made in this area, although several candidates were identified for further analysis and discussion, including sentinel fisheries, fisheries sampling, duplicate multi-species trawl surveys and single-species surveys. All regions reported that various "challenge" exercises have been carried out in recent years and that there was little "low-hanging fruit" in the form of resources that could be reallocated with little impact.

11.1 New technologies

Platforms, vessels and field laboratories, are the largest single cost for monitoring programs. It is appreciated that new technologies such as automated drogues can greatly reduce the cost of collecting oceanographic information. One example is Argo floats; however, there are no obvious technologies for automating the sampling of macrobiota. There is considerable concern about the poor reliability of CCG vessels. There is also concern about the extreme lack of flexibility in adjusting survey schedules.

The only potential opportunity to expand our monitoring and/or control costs of monitoring is to invest in new technological solutions and subject these to serious review/challenge as replacements for existing monitoring activities. “Scaling up” our expensive ship and people-based activities is not a realistic option. In the years ahead, we anticipate new, innovative efficient and effective ocean observation systems based on emerging technologies. These will include both in situ and remote sensing systems. The first generation of these is Project Argo, a global array of small autonomous profiling submarine robots. Argo provides global real time data sets of temperature, salinity, and currents. More recently, some Argo units are also reporting oxygen. Currently, the Canadian goal is to support 5% of the global array of 3,000 Argo floats, i.e. 150. The floats have a 5 year life. To meet our goal, we need to purchase 30 new floats a year, a capital cost of $600K. The current capital investment is $375K, enough for 19 floats. Operating costs to provide technical support for 150 floats is about $100K annually. New technology has the potential to significantly reduce the cost of many Pacific salmon freshwater enumeration programs. The results of trials of new acoustic devices (e.g. Dual Frequency Identification Sonar, DIDSON) are promising.

11.2 Frequency of monitoring

Frequency of monitoring was not considered to be a major opportunity for cost-saving because most areas are likely under-sampled. Nevertheless, it would be useful to conduct some analysis, which would include: inherent variability of the environment, error in the sampling method and generation time of the target organisms. In general, deep waters are sampled less frequently. For example, once every 3 to 5 years is considered to be adequate for abyssal waters in Lake Superior. Seals and Pacific hake are sampled two to three times per decade. Short-lived pelagic organisms like shrimp should be sampled annually. Multi-species trawl surveys are usually completed annually, although the Pacific multi-species trawl survey has been re-designed to cover the coast every two years.

Multi-species trawl surveys are conducted twice per year in the Eastern Scotian Shelf and Grand Banks. These seasonal surveys are useful for providing information on fish maturity and other things, including indices of abundance, but some rationalization may be possible. However, in some cases, Regions have designated these multiple surveys as being of very high priority, e.g. due to trans-boundary considerations.

Fixed stations are designed to measure seasonal changes and are optimally sampled at least twice monthly or at least until analysis demonstrates that a lesser frequency is appropriate. Analysis of continuous data from Station Papa indicated that a rate of three samples per year was adequate.

Sampling intensity of multi-species trawl surveys varies by ecosystem. The highest sampling rate, one set every 100 NM^2 is done in the Southern Gulf. This rate was calculated by statistical modeling to minimize variance of abundance estimates for key demersal species (cod and plaice). The sampling intensity on the Grand Banks and northeast Newfoundland Shelf is about half, one set every 200-250 NM^2. No analyses have been completed to identify the appropriate sampling intensity. Overall sampling intensity was considered to be very low. For example on the Scotian Shelf, 30 years of surveys provided a cumulative coverage (swept area) of <0.1% of the available area on the Shelf.

11.3 Strategic investment

Research programs can build on our investment in monitoring. These functions are not completely unrelated. As an example, we show a plot of “publications” arising from the long time series measurements at Ocean Station Papa. We attribute the large increase in publications in recent years to the “layering” of research programs, involving both DFO and academic partners, (e.g. WOCE (World Ocean Circulation Experiment), JGOFS (Joint Global Ocean Flux Study) and SOLAS (Surface Ocean-Lower Atmosphere Study)) onto the monitoring “infrastructure” (sampling platforms and long time series of data). Not all research projects can benefit from this, but many can and do.

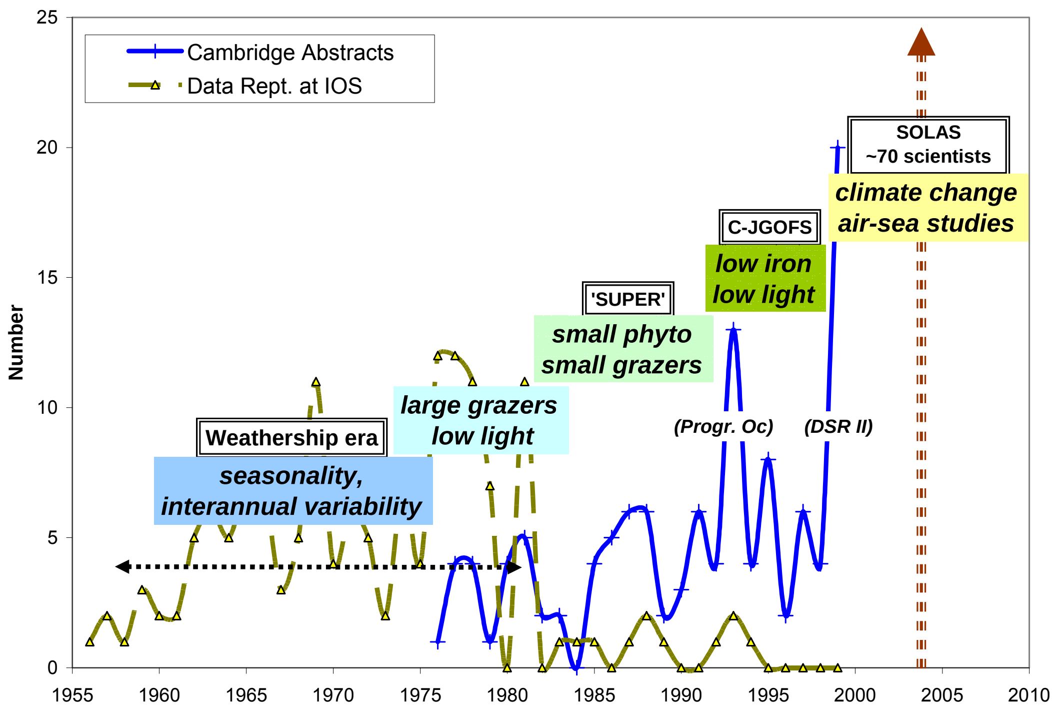

Figure 7. Number of publications arising from the long time series measurements at Ocean Station Papa.

We need to develop more partnerships with universities on monitoring. There needs to be a monitoring strategy that examines past and current monitoring activities for their role in understanding ecosystem value. This strategy would include an ecosystem modeling framework and field work to revisit sampling sites established in the International Biological Program (e.g. Marion Lake, Char Lake).

11.4 Multi-species surveys

On the East coast, historical activity suggests that all multi-species trawl surveys and the AZMP monitoring could be accommodated with the remaining two research trawlers, and should be able to continue within their normally allotted time periods. This approach assumes that about 40 sea days will be available for other surveys. Experience over the past decade points to another conclusion. The loss of one trawler will completely eliminate any flexibility in the vessel schedule to adjust for time lost for maintenance problems or search and rescue. For example in 2004-2005, 357 of 2,413 planned sea days were lost because of mechanical problems. These problems continue in the current year.

As mentioned above, there are overlapping surveys on the Eastern Scotian Shelf and the Grand Banks. Despite the duplication, these surveys provide information on stock characteristics such as distribution and maturity that are useful for stock assessments and ecosystem evaluations. In addition, the duplicated surveys give less intensive sampling than single-coverage surveys in other areas. The following nine multi-species trawl surveys are considered to be priority in the Atlantic Zone (note that the Unit 2 Redfish survey has already been discontinued):

Survey	Region	Days
1. 4T Multi-species	Gulf	28
2. 4VsW Multi-species	Maritimes	16
3. 4VWX Multi-species	Maritimes	31
4. 5Ze Multi-species	Maritimes	14
5. 2HJ3KLMNO Fall Multi-species	Newfoundland	142
6. 3LNO Spring Multi-species	Newfoundland	47
7. 3P Multi-species	Newfoundland	26
~~8. Unit 2 Redfish~~	~~Newfoundland~~	~~19~~
9. 3Pn-4RST Multi-species	Quebec	32
Total		336

In addition, the AZMP surveys in the various Regions have also been given high priority.

On the West Coast, there is only one science trawler. Any further reduction would mean that DFO would no longer have capability to conduct marine monitoring of demersal species.

There are several other surveys conducted by other countries that also provide overlap with DFO's multi-species surveys. Some further analysis is required before considering any harmonization among countries. These surveys include:

- Spanish trawl survey has some overlap on the nose and tail of the Grand Banks
- US surveys in the Gulf of Maine, of which there are two annual multi-species trawl surveys that overlap with DFO surveys.
- Canada-US surveys, primarily targeting hake, along the Pacific coast are conducted every three years and spend about 10-15 days in Canadian waters (already tightly harmonized).

11.5 Single-species surveys

Single species surveys are often considered to be for private benefit; however, two caveats are relevant. First, information is unavailable for species or areas that are not sampled by multi-species trawl gear, e.g. scallop, or near-shore zones. Second, species like capelin, herring and seals have important roles in the food web and knowledge of their status has obvious public benefit. Defining the boundaries of public good monitoring (or any work the Department undertakes) is critical to setting priorities. A list of single species surveys is provided in Table 6.

The loss of one research trawler on the east coast will reduce the availability of vessels for offshore monitoring surveys for a number of species. It was estimated that only about 25% of this work could be done with only two vessels instead of three.

Contingency plans will need to be developed for future vessel schedules. When there are maintenance problems, and extending dates is not possible or practical, priority should be given to completing surveys using a reduced sampling intensity. If this is not possible, priority should be given to completing physical oceanographic work required by AZMP.

All fisheries have some benefit for the public good, so it is important to establish a clear schedule of when and where surveys will occur. DFO Science will need to establish a level of standards, identifying the minimum frequency by which it would finance and conduct a fishery monitoring survey. This frequency would be based on the life-span and productivity of the species in question.

Most of these fishery surveys are conducted in areas or on species that are poorly covered by the multi-species surveys. As such, they provide information for more than stock assessments. For example some scallop and lobster trawl surveys are located in near-shore areas that are not covered by the larger multi-species surveys. This information is valuable for understanding issues related to climate change, invasive species and species at risk

More use could be made of many fishery surveys. For example, with a relatively small investment, some scallop and snow crab trawl surveys could operate more like multi-species surveys and provide more information on ecosystem status.

Small pelagic fisheries on the west coast have been able to initiate and fund their own surveys, e.g. Pacific herring fishery. It is hoped that small pelagic fisheries in the east coast become more autonomous and valuable.

Sentinel fisheries are a particular type of fishery survey where DFO Science provides funding directly to industry to conduct them. These surveys could never replace multi-species surveys and as such are considered to be lower priority. There may be opportunities to re-direct some of the sentinel fisheries towards monitoring activities which contribute more information on ecosystem status. One example might be the fixed-gear sentinel fishery in the southern Gulf. In the long-term, if fisheries like cod do recover, it may be possible to re-direct sentinel fisheries into other types of monitoring. These surveys are nearly a decade old but duplicate some information that is collected in the ecosystem multi-species trawl surveys. In the southern Gulf the fixed-gear component of survey is considered to be less of a priority. In the northern Gulf, the mobile-gear component is lower priority because the fixed gear covers near-shore areas that are unsampled by the ecosystem multi-species trawl survey. In Newfoundland, the sentinel surveys provide information in the near-shore environment, shoreward of areas covered by the trawl surveys. There may be a small amount of overlap in inshore areas with the ecosystem multi-species trawl surveys. There are other ancillary issues, such as credibility and trust of the industry, that sometimes result from sentinel surveys.

The Fisheries Science Collaborative Program is a source of funding for a number of fishery surveys and related research. It appears that successful projects have a tendency to develop into long-term monitoring projects. The upcoming review of FSCP in 2005-06 should re-consider the terms of reference of this program to include monitoring.

There are a number of industry-funded fishery surveys (the first two below) and fishery surveys where the industry is either given a quota or the industry uses part of their allocation to conduct them (the second three below):

- GEAC (Groundfish Enterprise Allocation Council) survey of 3Ps, 15 days
- GEAC redfish survey, 10 days
- 4X ITQ (Individual Trip Quota) survey, 3 vessels for 10 days each in near-shore waters
- 4Vs ITQ survey conducted by Fishermen and Scientists Research Society
- 0B/2G Shrimp and Greenland halibut, conducted by the shrimp-fishing industry
- Northern Gulf of Saint-Lawrence (CFAs 13-17) crab pot surveys

Single-species surveys need a careful analysis before devolving any costs to industry. In general, the high-value surveys for snow crab, shrimp, and scallop could be funded entirely by industry. Nevertheless, there are ethical and value issues at stake. At first, it looks appealing in practical term to have high-valued fisheries pay for their monitoring, while DFO continues to pay (subsidize) the cost for monitoring low-valued fisheries (i.e. non economical if they had to bear all costs), but clearly, not all Canadians would be treated on an equal footing. Similarly, fisheries that happen to be covered by the multi-species surveys would have a free ride (like the high-valued Gulf shrimp fishery) whereas those that are not (like the low-valued Gulf scallop fishery) would have to pay all costs. There needs to be extensive consultation regionally and nationally before assuming that industry can assume these costs. The single-species surveys provide more precise measurements of stock abundance and attributes that allow exploitation plans to be less conservative.

11.6 Fisheries sampling

This activity includes observer programs, landings and logbook data, port sampling and commercial sampling. This activity is a key component for assessing stock status when fishery-independent surveys are lacking. Fisheries sampling is also crucial for aiding decisions in managing fisheries, such as allocation of quotas among fleets and regions, resolving gear conflicts, understanding by-catch problems, identifying habitat issues and improving the value and timing of fisheries.

There are a number of areas where some economies could occur. For example, there is some duplication between Fisheries and Aquaculture Management and Science. Quota monitoring programs often do not enter information on fishing effort and location and the same data must be re-entered by Science or Economics. Fishery Officers examine catches for under-sized fish but do not collect length-frequency data. In addition, there have been significant advances in on-line data entry systems, where information can be entered on the wharf. More work is required to develop best practices and standardized procedures.

Fishery sampling is not complex and can be divested to industry as long as quality control is carefully validated. Industry is already involved in sampling landings at specific ports, e.g. GEAC.

Although either Policy and Economics or Corporate Services sectors of DFO collect catch data in many sport and commercial fisheries, Science programs in most regions compile similar data for species or fisheries not covered by DFO statistics. In the Arctic, Policy and Economics was the only sector that collected information on harvests, but this activity was discontinued in 1997. At present, science researchers must collect the harvest data if it is needed for stock assessment. There needs to be some harmonization between these two groups before it will be feasible to make further significant moves towards sharing these tasks with industry. Some careful analysis is required at the national level.

Finally, in the absence of any fishery-independent surveys, fisheries sampling provides the only information on stock status. Thus if surveys are reduced, fishery sampling must be maintained, or even expanded. However, it should be realized that surveys are essential to be able to monitor stock trends and this cannot be replaced by fisheries sampling alone.

11.7 Regional candidates

a) Arctic

Apart from EMAN-North (http://www.emannorth.ca/main.cfm) and Arctic Borderlands Ecological Knowledge Coop (http://www.taiga.net/coop/), there are no sustained *in-situ* monitoring programs in the Canadian Arctic.

Monitoring of contaminants is to be redefined, although most Canadians do not consider this activity to be low priority.

EC invests $1.25M in ice monitoring (Radarsat) through the Canadian Space Agency; of this amount $1.0M is billed to DFO (CCG). Emphasis has recently been put on community based monitoring programs for all coastal regions.

b) Atlantic

In addition to the activities listed above, nearly $3M is spent on monitoring Atlantic salmon, primarily in the fresh waters of Newfoundland. This activity needs to be rationalized Atlantic-wide. Conservation and Protection branch have transferred some responsibilities to the province. A similar transfer may be possible with the monitoring programs. The rationalization would consider the long-term operation of sampling sites, knowledge of sampling error in the abundance estimates and availability of protocols for data management and access.

c) Fresh water

The sea lamprey program is a very large investment. We need to understand exactly what is spent on monitoring and on application of lampricide. We also need to take advantage of this non-discretionary program to provide better insights on ecosystem status.

d) Pacific

Reduce station Papa line to two times per year and establish a fixed mooring to provide automated data capture.

Reduce sampling on La Perouse Bank to three times per year.

Delete the Strait of Georgia program, except for potential connections between the open ocean and the US cooperative research in Puget Sound.

e) Pacific salmon

Costs of some adult counting facilities and juvenile surveys could be transferred to stakeholders

There could be increased application of electronic monitoring to reduce overall costs, and the development of system-wide estimates of salmon run-size. The latter for example involves a test-fishery in the lower river (paid for via fish sales), application of genetic stock identification to the fish sampled, and accurate escapement monitoring at a couple of up-river sites. The total escapement to the river is estimated from enumeration and the ratio of stocks within the test-fisheries (currently being developed for Skeena and Nass rivers, and Fraser R sockeye by run-timing groups).

We frequently hear that Departmental funds are still largely the ‘back bone’ of funding for salmon monitoring, but this is not really true any longer. The portion of total costs covered by DFO, by species, varies from 25 to 95% but overall it is actually about 55%. There has been a very active push to develop partnerships but many area staff are concerned that we are expecting too much from partners. Nevertheless, many of the costs under fishery monitoring will be increasingly covered by the commercial and recreational portions of the industry.

The Pacific Salmon Treaty portion of the Pacific salmon budgets is based on a specific Treasury Board allocation and has specified uses. DFO is limited in how those funds can be reallocated. Further, any change in use becomes evident quickly because the funds support specific tasks in the 1999 PST Agreement and the PST advisors are very aware of what information should be available and when.

Stock ID for the management of marine commercial fisheries was considered to be a cost that could be transferred to industry.

Monitoring of sea lice is a cost that could be shared with the aquaculture industry.

11.8 Improvements to monitoring at little or no cost

There could be some optimization of the Government of Canada (GoC) fleet operations to improve monitoring of the oceans. Clearly, scaling-up dedicated vessel operations to improve monitoring is not an affordable option. One option is to explore the equipping and secondary tasking of vessels in the GoC fleet, primarily Canada Coast Guard (CCG), but also Department of National Defense (DND), to carry out ocean monitoring. The GoC has a large investment in keeping ships at sea with search and rescue and increasingly, security as their primary tasking. One approach would be to develop a new policy that gives priority to secondary tasking of GoC vessels to carry out monitoring. This policy would require some investment in instrumentation, training of personnel and a willingness to make an active contribution. For the monitoring program, a long term commitment is a requirement. We note that large vessels essentially circumnavigate Canada twice a year, providing a opportunity to carry out some monitoring of all of Canada's oceans (Atlantic, Pacific, and Arctic) on a annual basis.

Another initiative that would improve our monitoring capability, without much additional cost would be to establish a formal framework to produce ecosystem status reports in a regular manner across the nation. This framework would contribute to resolving issues of data availability, security and access and to developing tools required for synthesizing diverse data sets and linking environmental information and human activities to decisions that are made in resource management. The security of data in the freshwater environment is particularly complex.

Monitoring programs need to be flexible, testable and adaptable. The frequency and sampling intensity of monitoring activities need to be evaluated and justified. It is understood that there may not be many savings here, simply an optimization between frequency and intensity.

Currently, many data sets depend upon the knowledge and leadership of the principle investigator. The team felt that mentoring and succession plans should be developed for all important monitoring activities at the program and project levels. In some cases, there is urgent need for these plans.

DFO monitoring programs are not visible and need to be clearly communicated. We need to do a better job at explaining their relevance to the average Canadian. Examples of effective national programs are found in UK, Korea and Norway. Annual bulletins prepared by the Atlantic Zone Monitoring Program (AZMP) could be expanded and simplified in order to reach a broader audience. Importance of long-term time series in monitoring needs to be emphasized.

Our existing heavy reliance on dedicated ship-based surveys could be replaced by an increasing use of autonomous instrumentation and technology (e.g. Argo floats; cabled observatories; biological monitoring from existing EC/DFO buoy network). This doesn't mean our requirements for ships will disappear. Dedicated ship time will be augmented by various platforms of opportunity. Finally, fixed stations and sections could be replaced or at least augmented by variable "geometry" (time and space) sampling and data-assimilating numerical models. Increasingly the indicators used for decision-making will be output from such models and direct measurements will be used to constrain and validate them. These trends have already taken place at the Meteorological Services of Canada.

12. Conclusions

Almost one-third of the DFO Science budget is spent on aquatic monitoring, yet there is no integrated national monitoring program. The delivery models vary widely across the country. The most effective model is the Atlantic Zone Monitoring Program and this approach needs to be expanded nationally for all regions. The most critical issue is to balance the need to conduct more monitoring for better understanding of our aquatic ecosystems with the increased cost and decreased reliability of at-sea platforms. A second issue is to ensure that we have national standards and protocols for all monitoring programs. Greater clarity and harmonization of fisheries sampling and single-species surveys needs to be achieved across all sectors of the department. We also need to integrate aquatic monitoring across all federal and provincial agencies. There are a number of activities that could be improved but it is unlikely that they would result in significant savings. New monies will be required to expand monitoring in northern regions and near-shore coastal and littoral areas and to improve monitoring for integrated management, oceans management, marine protected areas, quality of habitat, invasive species and understanding aquatic food webs.

***Table 1.* Description of monitoring activities**

Category	Description
Age and growth labs	Aging labs exist in all regions and are in support of stock assessment activities. These labs are well-managed and provide consistent long-term information on analysis of bones, scales and other tissues. Some of our longest historical time-series of growth and environmental conditions come from this information. There could be some rationalization of this activity such as reduced sample size from commercial sampling, with greater emphasis on samples collected from multi-species trawl surveys.
Bathymetric surveys	These surveys are considered to be a monitoring activity only in the St. Lawrence River because of rapid sedimentation.
Contaminants monitoring	Monitoring of contaminants in water, sediment and biota is a major concern of most Canadians. The capabilities/capacity/expertise of other government departments to carry out these activities in aquatic and marine environments is highly variable.
CPR lines	Continuous Plankton Recorders provide long time series of information on the pelagic zone.
Diet surveys	These surveys can provide an indication of significant changes in the food web. In other parts of the world, such surveys are conducted periodically (e.g. ICES – Year of the Stomach).
Fish counting facilities	Many of these facilities employ people in isolated parts of the country. The decision to maintain these facilities is a regional one. However, greater visibility of the information collected at these facilities would be beneficial.
Fish health surveys	These surveys are a new initiative to demarcate zones of similar OIE-identifiable-disease characteristics.
Fisheries sampling, landings, logbooks and observer programs	This activity could receive greater support from the private sector. The sampling is not useful unless it is done properly. An effective model for sampling and auditing needs to be developed before this activity can be successfully transferred to industry. Other savings could be achieved if quota monitoring and port sampling were combined and subject to an audited quality assurance program. Catch data in sport and commercial fisheries are compiled by most regions. The program is mostly delivered by others but Science has taken some responsibilities in most regions. Logbooks are also part of this responsibility. This activity should receive greater support from the private sector.
Fixed stations (See map for locations)	These sites include our most important monitoring activities and include profiles of physical (temperature, salinity), chemical (nitrate, nitrite, phosphate, silicate, oxygen) and biological (fluorescence, chlorophyll a) variables. Optimally, they are sampled bi-weekly; more often they are sampled once or twice per year. Station 27, Station Papa, the Experimental Lakes Area and some fixed river stations provide decades of information about long-term changes in the aquatic environment. These sites can be visited systematically and opportunistically and provide an excellent base to launch cost-effective targeted research programs.
Multi-species river surveys	Most of these are conducted using electro-fishing equipment and provide indications of fish species composition
Multi-species trawl surveys	Most of these surveys were initiated over 30 years ago with a focus on identifying the abundance and distribution of commercial demersal fishes. Over the years, the surveys have been expanded to do more than just monitor

Category	Description
	commercial groundfish. They now include oceanographic observations, measurements of marine environmental quality, collection of biological samples for studies of growth, diet, and disease and the identification and abundance of >100 benthic, demersal and pelagic fish and invertebrate species.
Other monitoring	Examples would include aerial surveys of seals
Plankton, larval, juvenile surveys	These surveys provide valuable information on the pelagic ecosystem. They are considered lower priority than the multi-species surveys but careful analysis and identification of key clients are required before discontinuing any of them.
Satellite, remote sensing	Currently, there are four laboratories with this capability. It may be timely to seek future support from DND who are clearly national leaders in this technology.
SCUBA surveys	These surveys provide detailed information for small components of the benthic ecosystem. They are often conducted on an opportunistic basis and because of their narrow scope are considered to be of lower priority than more broadly-based surveys.
Sections (See map)	This activity is to collect a series of profiles along a set transect of physical (temperature, salinity), chemical (nitrate, nitrite, phosphate, silicate, oxygen) and biological (fluorescence, chlorophyll a) variables. Sections are sampled once per season or less.
Sentinel surveys	In some cases these surveys duplicate information collected from multi-species trawl surveys. Lower priority or lower information content sentinel surveys include the fixed gear survey in southern Gulf, the mobile gear survey in the northern Gulf, the fixed gear survey in the Scotian Shelf and the fixed gear survey in non-coastal areas that are covered by the multi-species trawl surveys around Newfoundland and Labrador.
Ships of Opportunity	Data collected from vessels that are carrying out other functions. Includes ferries, commercial vessels and Coast Guard ships. Measurements vary, but typically include surface temperature, salinity, nutrients, fluorescence and some biogeochemical parameters.
Short-term issue-driven monitoring	Short-term issue-driven monitoring includes projects that meet the following criteria: duration < 5 years, science function ≥ 50% monitoring and DFO expenditure ≥ $10,000. There are a number of projects in this category including monitoring impacts of oil-gas exploration, aquaculture, and new fisheries. These have been generally excluded from the report.
Single-species surveys	These surveys, in their current format, generally provide less information on the ecosystem than the multi-species surveys. Surveys of high value species such as scallop, snow crab, shrimp are likely candidates to be assumed by the private sector. Surveys of ubiquitous forage species are in the public interest and should be at least partly covered by DFO. It is noted that snow crab surveys using a Nephrops or similar trawls could provide significant insights into benthic communities but time and space limitations on board the vessels used do not permit full sampling.
Tagging and genetics	Long-term tagging and genetic methods are used to identify stock origin for interceptory or mixed-stock fisheries. Industry involvement has worked here (platforms, money for tag rewards etc.).
Taxonomy & reference labs	These labs are available in four regions. Some rationalization of this activity could occur nationally.

Category	Description
Technical support & equipment	Technical support is required for the calibration and maintenance of monitoring equipment. Most laboratories have this capability and there could be some rationalization nationally.
Thermo-graphs	These networks are an important source of information on the characteristics of water in coastal areas.
Water level gauges	The network of gauges provides valuable information on sea-level change. See map for locations.

***Table 2*. Expenditures on monitoring activities by location: DFO expenditures in top table; partner expenditures in bottom table.**

Activity	*Atlantic*	*Arctic*	*Fresh water*	*Pacific*	*Pacific salmon*	*Total*
Multi-species trawl surveys	6542	142		6989	0	13673
Multi-species river survey			15		0	15
Single-species surveys	1771		1296	327	3678	7072
Sentinel surveys	3772				0	3772
Plankton, larval, juvenile surveys	569		579	30	716	1894
SCUBA surveys	20			883	0	903
Diet surveys	74			0	0	74
Fish health surveys	244		40		0	284
Fixed stations	778		430	460	0	1668
Sections	2500			2394	0	4894
Water level gauges	393	302		176	0	871
Bathymetric surveys	265				0	265
Thermographs	178			114	219	511
Satellite, remote sensing		79		60	0	139
CPR lines	122			20	0	142
Technical support & equipment	1031		727	200	311	2269
Taxonomy & reference labs	60			0	0	60
Fisheries sampling	2198	94		385	2915	5592
Age and growth labs	472			280	186	938
Fish counting facilities			2698	265	1570	4533
Ships of Opportunity	28			20	0	48
Tagging and genetics	170	96			755	1021
Contaminant monitoring	615		97	0	0	712
Short-term, issue-driven monitoring	758		245	1230	0	2233
Other monitoring activities	1616			254	742	2612
Toxic algae	116				0	116
Total	24292	713	6127	14087	11092	56310

Activity	*Atlantic*	*Arctic*	*Fresh water*	*Pacific*	*Pacific salmon*	*Total*
Multi-species trawl surveys	52	187		7509	0	7748
Multi-species river survey	0				0	0
Single-species surveys	579		568	288	1615	3050
Sentinel surveys	21				0	21
Plankton, larval, juvenile surveys	35			5	314	354
SCUBA surveys	2			1000	0	1002
Diet surveys	0			0	0	0
Fish health surveys	29				0	29
Fixed stations	39		270	700	0	1009
Sections	0			200	0	200
Water level gauges	5			0	0	5
Bathymetric surveys	0				0	0
Thermographs	0			78	96	174
Satellite, remote sensing		12		50	0	62
CPR lines	154			150	0	304
Technical support & equipment	0		290		137	427
Taxonomy & reference labs	0			0	0	0
Fisheries sampling	57	275		10700	1280	12312
Age and growth labs	1			60	40	101
Fish counting facilities			218	650	690	1558
Ships of Opportunity	0			80	0	80
Tagging and genetics	52	215			332	599
Contaminant monitoring	0		57	0	0	57
Short-term, issue-driven monitoring	386		45	1440	0	1871
Other monitoring activities	90				326	416
Toxic algae	0				0	0
Total	1502	688	1449	22910	4830	31379

Table 3. **Expenditures on monitoring activities by region: DFO expenditures in top table; partner expenditures in bottom table**

Activity	Newfoundland	Maritimes	Gulf	Quebec	Central	Pacific	Total
Multi-species trawl surveys	4300	1110	539	593	142	6989	13673
Multi-species river survey			15			0	15
Single-species surveys	492	717	319	243	1296	4005	7072
Sentinel surveys	2363	16	658	735		0	3772
Plankton, larval, juvenile surveys	248	0	81	240	579	746	1894
SCUBA surveys		0		20		883	903
Diet surveys		26		48		0	74
Fish health surveys		0	228	16	40	0	284
Fixed stations	323	160	111	184	430	460	1668
Sections	1192	853		455		2394	4894
Water level gauges		238	7	148	302	176	871
Bathymetric surveys		0		265		0	265
Thermographs		46	94	38		333	511
Satellite, remote sensing		0		79		60	139
CPR lines		122		0		20	142
Technical support & equipment	622	233	57	119	727	511	2269
Taxonomy & reference labs		60		0		0	60
Fisheries sampling	815	669	297	417	94	3300	5592
Age and growth labs	225	76	122	48		466	938
Fish counting facilities	2563	101	34	0		1835	4533
Ships of Opportunity		28		0		20	48
Tagging and genetics	100	0	70	0	96	755	1021
Contaminant monitoring	500	0		115	97	0	712
Short-term, issue-driven monitoring	50	143	36	529	245	1230	2233
Other monitoring activities	1184	8	160	264		996	2612
Toxic algae				116			116
Total	14977	4606	2828	4672	4048	25179	56310

Activity	Newfoundland	Maritimes	Gulf	Quebec	Central	Pacific	Total
Multi-species trawl surveys		0	52	0	187	7509	7748
Multi-species river survey			0	0		0	0
Single-species surveys		333	246	0	568	1903	3050
Sentinel surveys		20	0	1		0	21
Plankton, larval, juvenile surveys		0	34	1		319	354
SCUBA surveys		0		2		1000	1002
Diet surveys		0		0		0	0
Fish health surveys		0	21	8		0	29
Fixed stations		39	0	0	270	700	1009
Sections		0		0		200	200
Water level gauges		0	0	5		0	5
Bathymetric surveys		0		0		0	0
Thermographs		0	0	0		174	174
Satellite, remote sensing		0		12		50	62
CPR lines		154		0		150	304
Technical support & equipment		0	0	0	290	137	427
Taxonomy & reference labs		0		0		0	0
Fisheries sampling		0	51	6	275	11980	12312
Age and growth labs		0	0	1		100	101
Fish counting facilities		98	120	0		1340	1558
Ships of Opportunity		0		0		80	80
Tagging and genetics		0	52	0	215	332	599
Contaminant monitoring		0		0	57	0	57
Short-term, issue-driven monitoring	300	51	1	35	45	1440	1871
Other monitoring activities		6	25	59		326	416
Toxic algae				0			0
Total	300	700	602	129	1907	27740	31379

Table 4. **The framework for ecosystem-based management organizes the operational strategies and associated performance indicators under sub-objectives of the three conservation objectives.**

Objective	Operational strategy	Performance indicator
Sub-objective		
•		
Productivity		
▪ *ensure that the activity does not cause unacceptable reduction in* ***productivity*** *of each component (primary, community and population) so that it can play its historical role in the functioning of the ecosystem*		
Primary	▪ Limit alteration of nutrients affecting primary production	essential nutrient concentrations
Community	▪ Limit removals from any trophic level with respect to trophic demands of higher levels	trophic level catch biomass
	▪ Limit total removals within system production capacity	total catch biomass
Population	▪ Keep exploitation moderate	fishing mortality rate
	▪ Permit sufficient spawning biomass to evade exploitation	spawning biomass
	▪ Promote rebuilding when biomass is low	biomass change
	▪ Manage size/age/sex of capture	% size/age/sex in catch
	▪ Prevent disturbance during spawning	areas/seasons fishing activity in spawning
	▪ Manage discarding	discarded catch
Biodiversity		
▪ *ensure that the activity does not cause unacceptable reduction in* ***biodiversity*** *by maintaining enough components (biotopes/seascapes, species and populations) to preserve the structure and natural resilience of the ecosystem.*		
Biotopes/seascapes	▪ Limit disturbance of seascapes/biotopes	% area and frequency disturbed
Species	▪ Limit incidental mortality	% bycatch; absolute bycatch; bycatch mortality rate
	▪ Minimize spread and impact of invasive species	change in distribution of invasive species
Population	▪ Maintain components of utilized species	component catch as a % of component biomass
Habitat		
▪ *ensure that the activity does not cause unacceptable modification to* ***habitat*** *that is difficult or impossible to reverse in order to safeguard the 'container' (both physical and chemical properties) of the ecosystem*.		
Bottom	▪ Limit disturbance to nursery grounds, spawning grounds, etc.	% area and frequency disturbed
Water Column	▪ Minimize loss of gear and ghost fishing (long lines, nets)	rate of encounter with lost gear *and/or* amount of lost gear
	▪ Reduce/control noise level and frequencies with respect to species of risk, e.g., marine mammals	relative to distribution of the disturbance distribution of species of risk

Table 5. **The estimated costs of establishing four new routes surveys with continuous plankton recorders (CPR). These costs include the identification and data entry of species caught in the recorders.**

Route Title	Frequency	Setting-up Cost $	Running Cost $
1,000 km transect east Canadian Arctic	At least twice per annum	30,000 number need to be examined again	10,800
1,000 km transect west Canadian Arctic	At least twice per annum	30,000	10,800
8 x 1,000km transects St Lawrence	8 times per annum	44,000	61,200
8 x 1,000km transects Great Lakes	8 times per annum	44,000	70,000
DFO financial contribution to PICES CPR program (California to Alaska and Vancouver to Japan)	2 times per year (transpacific route) 4 times per year (north-south route)	In place, largely funded by North Pacific Research Board	75,000 (annual)

Table 6. **List of vessels and surveys conducted annually in each of DFO six regions.**

a) Pacific Region

J.P. Tully	o North Pacific and Shelf Seas oceanographic monitoring (physical and biological parameters), 116 days
Neocaligus	o Inlet ecosystem surveys (clams, sea otters, invasives), 25 days
	o Multi-species trawl and trap surveys in Juan de Fuca, Strait of Georgia, Howe Sound, Jervis Inlet, 25 days
	o 3 shrimp trawl surveys (Barkley Sound, Prince Rupert, Knight Inlet), 48 days
	o Prawn survey, Howe Sound, 12 days
	o Crab survey, Fraser Delta/Boundary Bay, 13 days
Vector	o Multi-Beam and benthic habitat classification surveys in coastal and Shelf seas of British Columbia, 84 days
Ricker	o Multi-species trawl surveys with oceanographic sampling in WCVI and Dixon Entrance, Hecate Strait and Queen Charlotte Sound, 40 days
	o Shrimp survey, WCVI/QC Sound, 28 days
	o Hake survey (triennial), 76 days
	o Continental shelf and high seas juvenile salmon surveys (coast-wide), including oceanographic sampling 116 days (although >5 years, this survey is better described as research and not monitoring; partners help defray a significant portion of the ship time and program costs)

b) Central and Arctic Region

Experimental Lakes Area	o Comprehensive monitoring of 5 Boreal Shield lake ecosystems, 365 days

c) Quebec Region

Creed	o Oceanographic measurements in the Gulf of St. Lawrence (part of AZMP), 44 days
Needler	o Multi-species trawl survey in the Gulf of St. Lawrence (3Pn and 4RST), 29 days
Smith	o Multi-beam soundings in St. Lawrence Estuary, 244 days
CG-3	o Multi-beam soundings in St. Lawrence Estuary, 244 days
Coriolus 2	o Oceanographic measurements in Gulf of St. Lawrence (part of AZMP) surveys involving physical and biological measurements, 62 days
Calanus II	o Shrimp survey, Rimouski, 7 days
	o Greenland halibut survey, St. Lawrence Estuary, 9 days
	o Scallop survey, Mingan Islands, 23 days
	o Snow crab survey, 4S, 16 days
	o Scallop survey, Magdalen Islands, 14 days
	o Lobster and Rock crab surveys, Magdalen Islands, 13 days
	o Winter recreational fishery survey, Saguenay Fjord, 16 days
	o Shrimp survey, Northern Gulf, 14 days
	o Snow crab survey, Northern Gulf, 13 days

Templeman	o Herring survey, 4R, 21 days

d) Gulf Region

Needler	o Multi-species trawl survey in Southern Gulf, 28 days
Creed/Calanus	o Herring acoustic survey, 40 days (20 days on each vessel)
Opilio	o Northumberland Strait – multi-species, 25 days
Charters	o Snow crab surveys, 40 days

e) Maritimes Region

Hart	o Toxic algal bloom monitoring in Bay of Fundy, 4 days
	o Three scallop surveys, Bay of Fundy, 53 days
Hudson	o Two oceanographic surveys (physical, chemical and biological measurements) on the Scotian Shelf (part of AZMP), 22 days
Matthew	o Multi-beam sounding in Atlantic Canada, 135 days
Needler	o Multi-species trawl surveys on Scotian Shelf and in Gulf of Maine area, 62 days
	o Herring survey Georges Bank, 11 days
Opilio	o 15 Oceanographic surveys (physical, chemical, and biological measurements) at fixed station in Shediac Valley, 15 days
Small CCG vessel	o 26 Oceanographic surveys (physical, chemical, and biological measurements) at fixed station off Halifax (part of AZMP), 26 days

f) Newfoundland and Labrador Region

Hudson	o Oceanographic survey (physical, chemical, and biological measurements) on Newfoundland and Labrador Shelves (part of AZMP), 19 days
Teleost	o 2 Oceanographic surveys (physical, chemical, and biological measurements) on Newfoundland and Labrador Shelves (part of AZMP), 31 days
	o Multi-species trawl surveys in 2HJ3KLMNO (including gear trials); 87 days for fall survey.
	o Capelin acoustics survey in 3KNO (this is not a survey for a specific user group but rather to track “forage” abundance), 20 days
	o Scallop survey, 4R/3Ps/3NO, 15 days
	o Redfish survey, 3Ps, 19 days
Templeman	o Multi-species trawl surveys in 3Ps and 3LNO (including gear trials), 147 days
Shamook	o Trinity Bay Ecosystem surveys
	o 6 oceanographic surveys (physical, chemical and biological measurements) part of AZMP, 41 days
	o 4 Snow crab surveys, 3KL, 64 days
	o Cod distribution survey, 3KL, 16 days