



## ARCHIVED - Annual Performance Report 2007-2008

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# Genomics R&D Initiative

ANNUAL PERFORMANCE REPORT 2007-08

*The Genomics R&D Initiative is a national program that coordinates federal science departments and agencies in the field of genomics to support key national interests in human health, agriculture and food safety, environment and natural resources management.*



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# Executive Summary



The key objective of the Genomics R&D Initiative (GRDI) is to sustain intramural genomics research in support of key federal public policy objectives in areas of national interest (human health, agriculture and food safety, environment and natural resources management), to strengthen innovation, promote global competitiveness, and ensure sustainability for the benefit of all Canadians. It leverages resources through extensive research collaborations in Canada and internationally and directly involves:

- **National Research Council Canada (\$6M/yr)**
- **Agriculture and Agri-Food Canada (\$6M/yr)**
- **Health Canada and the Public Health Agency (\$4M/yr)**
- **Natural Resources Canada (\$2M/yr)**
- **Environment Canada (\$1M/yr)**
- **Fisheries and Oceans Canada (\$0.9M/yr).**

The initiative has been funded for three-year cycles: Phase I (1999-02), Phase II (2002-05), Phase III (2005-08), and Phase IV (2008-11). The GRDI ADM Coordinating Committee, chaired by NRC, includes members from the organizations receiving funding and from Industry Canada, and is mandated to provide strategic direction and oversee the collective management of the initiative. Involving the same organizations, an interdepartmental working group supports the ADM Coordinating Committee and addresses evaluation and reporting requirements related to the initiative.

Investments from the GRDI have provided a strong foundation for public sector scientists to explore promising research avenues towards Canada's economic goals and social wealth. Fiscal year 2007-08 was the third and last year of Phase III funding. Consistent with their performance of previous years, participating departments have once again made excellent progress towards the objectives set for the GRDI and have delivered exciting results with impact on the science of genomics and benefits for Canadians through direct applications.

This Annual Performance Report for 2007-08 follows the Results-based Management and Accountability Framework (RMAF) for the GRDI, which formalizes common measurement criteria according to requirements of the Treasury Board Secretariat.

It illustrates how the GRDI, working with many research partners in Canada and internationally (**Tables 3 and 4**), has supported the development of vast amounts of new knowledge and innovative technologies targeted at improving human health, environmental and natural resource management, agriculture, and food safety. These are exemplified in the following **Application Highlights**, summarized in **Annex 3** of Appendix A, and illustrated by the summary statistics of outputs in **Annexes 2, 4 and 5** of Appendix A.

# Application Highlights

## HEALTH

A robust method to quantify a specific influenza virus antigen was developed and is now patented. This will allow the efficient release of influenza vaccines for annual vaccination campaigns and for a rapid response in the case of a potential pandemic.

Scientists have developed an innovative technology for the rapid and affordable detection of Salmonella. Collaborative agreements are in place with the Veterinary Laboratory Agency (VLA) in the United Kingdom to optimize and validate the technology. Upon completion of this work, the product will be sold and distributed in Europe and North America through Identibac, a commercial company supported by the VLA.

Years of research have produced evidence that immunotherapy could successfully treat cancer. A new family of antibodies were discovered that can play a role in preventing tumour invasion by blocking the function of a glycoprotein associated with human cancers. A Canadian company is seeking to commercialize these clusterin-specific antibodies for worldwide therapeutic and diagnostic applications.

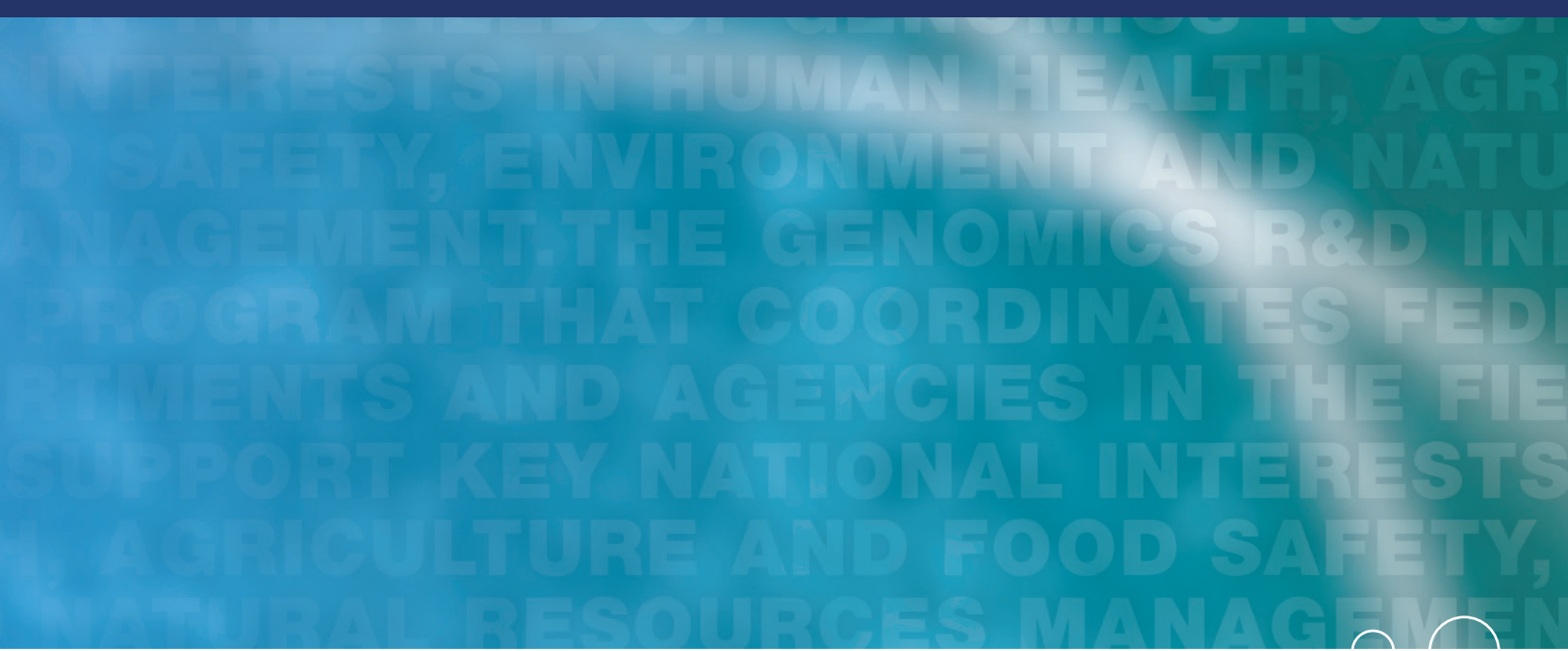
Genomics information was used to analyse the bacterial composition of the large intestine of humans and its response to fermentable dietary material, thus forming the basis for understanding the role of prebiotics and probiotics in foods. This information has helped shape Health Canada's policies on probiotics, as well as policy decisions on the addition and labelling of this material in food products, providing Canadians with choices on the foods they consume.

## AGRICULTURE

A wheat gene was discovered that provides resistance to Fusarium Head Blight, a disease that has been directly responsible for a cumulative loss of over \$1.5 billion at the farm-gate since 1996. The gene also has potential to provide broad based resistance to other diseases that could threaten Canadian crops.

The recent discovery of a genetic factor in legumes that responds to signals from nitrogen fixing bacteria was significant. Legumes generally do not require nitrogen fertilization because of their symbiotic relationship with these bacteria. The acquisition of nitrogen fixing capacity by non-legume plants would allow them to make their own fertilizer, and would considerably reduce the use of fossil fuels and synthetic materials by agriculture.

A canola gene was discovered that can boost the productivity and resilience of canola. The gene has a profound impact on plant growth and its over-expression in trials resulted in taller, stronger and more durable plants with increased seed production and an average yield of oil that exceeded regular control plants by roughly 23 percent.



## ENVIRONMENT

Toxicogenomic methods were developed and applied to aquatic systems to rapidly identify microbial pathogens such as those indicative of contamination by human, animal or agricultural fecal matter. These methods are now being used by governments (municipal/provincial/federal) to effectively manage their water sources.

Through the development and use of a DNA microarray (tool for DNA expression), border enforcement officials were successful in identifying caviar originating from rare and protected species rather than from a legal species as had been reported. Border officials were thus able to obtain a conviction on the dealer for importing illegal caviar.

## NATURAL RESOURCES

The large genetic baseline datasets developed by GRDI scientists for Pacific salmon are now used for the most intensive genetic management of fisheries on a real-time basis in the world. Over 10,000 chinook, sockeye and coho salmon samples are analyzed each year to manage fishery openings. This enables Canada to maximize catch under the US/Canada Pacific Salmon Treaty allocations while maintaining strict harvest limits on stocks for conservation and results in increased annual revenue of several million dollars to the fisheries.

A genomics based kit developed by GRDI scientists to detect and track the fungus that causes sudden oak death is now used operationally by the CFIA and the USDA-APHIS. This disease, first reported in the mid-1990s in southwest United States, is a threat to Canada's hardwood forests and has resulted in losses of hundreds of millions of dollars to Canada and US nurseries. The toolkit enables Canadian nurseries to certify that their products are free of the disease and continue to export their products.

# Genomics R&D Initiative (GRDI) – Program Profile

The research field of genomics and related sub-disciplines has profoundly transformed the study of life processes since its early days twenty years ago. Genomics is the science that studies DNA sequences, the functions of the tens of thousands of genes found in living organisms, and the complexity of their multiple interactions. It provides an unprecedented level of understanding that already contributes broad applications to improve the quality of human life, Canada's economy, and environmental sustainability. As genomics applications keep breaking new grounds, advances in this field are broadly recognized as a true scientific revolution.

The Government of Canada recognizes the importance of genomics research and has established the intramural GRDI (\$19.9 million/yr) in January 1999 to support genomics research in six federal government organizations.

The Government of Canada has also supported the non-for-profit organization Genome Canada and its regional centres (\$840M since 2000) to advance large-scale genomics research and enhance Canada's international position. This investment was leveraged to more than \$1.6 billion with co-funding from partners.

*As genomics applications keep breaking new grounds, advances in this field are broadly recognized as a true scientific revolution.*

## Overview

The key objective of the GRDI is to sustain intramural genomics research in support of key federal public policy objectives in areas of national interest (human health, agriculture and food safety, environment and natural resources management), to strengthen innovation, promote global competitiveness, and ensure sustainability for the benefit of all Canadians. Knowledge from genomics research generates powerful tools to support operational and regulatory mandates, to facilitate decisions related to key federal public policy objectives in all sectors of life sciences, and to develop innovative applications for the benefit of Canadians.

These applications include:

- Improved diagnostics and understanding of human infectious and chronic diseases;
- Improved crop quality for multiple end uses including bioenergy and bioproducts, and adaptation to environmental change, focusing on cereals, oilseeds and legumes;
- Environmentally sustainable strategies for the control and diagnostics of pests and pathogens in the face of increasing threats from insect and disease outbreaks in crops and forests;
- Forensic tools to monitor fish resources "from ocean to plate" for sustainable harvesting according to certification standards, traceability, identification of illegally harvested or mislabelled fish, and access to global markets;
- Baseline genomic population data and metagenomics tools for environmental monitoring, remediation, and monitoring of aquatic animal diseases;
- Knowledge on the effects of contaminants on soils, sediments, birds and aquatic life allowing to monitor the health of Canada's ecosystems and guide regulatory decisions;
- Genomic markers to study gene-gene, gene-drug and gene-environment interactions in the investigation of infectious and chronic diseases; and
- Knowledge on the unique genetic richness of Canadian forests to identify genes controlling desirable attributes in trees and provide reliable tools for forest managers.

The initiative also supports socio-economic and ethical studies related to genomics applications, studies in support of regulatory oversight involving applications containing genomics data, as well as outreach activities to facilitate access to clear and accurate information on genomics R&D.

The GRDI has been funded for three-year cycles: Phase I (1999-02), Phase II (2002-05), Phase III (2005-08), and recently Phase IV (2008-11) and involves NRC (\$6M/yr), Agriculture and Agri-Food Canada (\$6M/yr), Health Canada and the Public Health Agency (\$4M/yr), Natural Resources Canada (\$2M/yr), Environment Canada (\$1M/yr) and Fisheries and Oceans Canada (\$0.9M/yr), as shown in **Table 1**.



**Table 1: Funding Allocation**

DEPARTMENT/AGENCY	PHASE I 1999-2002	PHASE II 2002-2005	PHASE III 2005-2008
Agriculture and Agri-Food Canada	\$17,000,000	\$18,000,000	\$18,000,000
Environment Canada	\$3,000,000	\$3,000,000	\$3,000,000
Fisheries and Oceans Canada	\$2,500,000	\$2,700,000	\$2,700,000
Health Canada / Public Health Agency of Canada	\$10,000,000	\$12,000,000	\$12,000,000
National Research Council Canada	\$17,000,000	\$18,000,000	\$18,000,000
Natural Resources Canada	\$5,000,000	\$6,000,000	\$6,000,000
Medical Research Council <sup>1</sup>	\$500,000	-	-
<b>TOTAL</b>	<b>\$55,000,000</b>	<b>\$59,700,000</b>	<b>\$59,700,000</b>

1 Precursor to the Canadian Institutes of Health Research (CIHR) – one time allocation in fiscal year 1999-2000 to assist in the establishment and support of a Genome Canada Secretariat.

To maximize the quality and relevance of research funded under the GRDI, each department uses a competitive program proposal and approval process including scientific peer reviews. Extensive research collaborations in Canada and internationally allow strong leverage of resources and expertise, and the pursuit of larger-scale multi-disciplinary discovery enterprises (as described in **Tables 2, 3 and 4**, and **Management on page 10**).

### Governance

An interdepartmental Assistant Deputy Minister (ADM) Coordinating Committee has been established to oversee the collective management and coordination of the federal GRDI. The Committee ensures that effective priority setting mechanisms are established within departments, and that government objectives and priorities are addressed. The Committee also ensures that common management principles are implemented and horizontal collaborations between organizations are pursued wherever relevant and possible. The committee includes members from each of the organizations receiving funding, as well as a representative from Industry Canada and a guest representative from Genome Canada.

An interdepartmental GRDI Working Group supports the work of the committee. The mandate of the working group is to provide recommendations and advice to the ADM Coordinating Committee regarding strategic priority setting and overall management of the GRDI. The working group also supports evaluation and reporting requirements related to the Initiative.

The National Research Council coordinates interdepartmental activities to manage the GRDI, including the development and implementation of the Results-based Management and Accountability Framework (RMAF), and chairs both the Coordinating Committee and the Working Group.

### Formative Evaluation

A formative evaluation of the Genomics R&D Initiative was conducted in 2006 by a private consultant (Performance Management Network Inc) concluding to its overall success and relevance to deliver well-managed credible research for policy, regulation and other government decisions. The evaluation confirmed that most of the six government departments have had limited capacity to carry out genomics research before the implementation of GRDI, and that GRDI had been successful in filling the gap. Departments supported by GRDI funds now have the human resource capacity as well as the tools, equipment, infrastructure and networks required to undertake genomics R&D and participate in broader, high-impact programs established through formal and informal collaborations with Canadian and international organizations (governmental, university, non-governmental and private sector organizations). The review also concluded to the legitimate and necessary role for government in genomics R&D, and to the complementing nature of GRDI and other federal or provincial initiatives in this area without overlap or duplication.

A key recommendation of the evaluation was thus to not only continue support for the Initiative on an ongoing basis, but also to increase its funding base to meet the ever evolving need for genomics R&D inside government laboratories. With this came other key recommendations: that government should identify mechanisms to strengthen the strategic direction for the GRDI to address national priorities, and take steps to ensure that accountability and performance reporting continue as key elements of the initiative.

The GRDI ADM Coordinating Committee committed to address the recommendations in a management action plan in accordance with Treasury Board Evaluation Policy and progress is reported annually in the NRC Departmental Performance Report.





## Results-based Management and Accountability Framework

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A Results-based Management and Accountability Framework (RMAF) for the GRDI formalizes the commitment of the six departments and agencies involved in the Initiative to report on common performance indicators and guides the structure and content of this 2007-08 Annual Performance Report, which covers year 3 or Phase III funding.

The RMAF logic model reflects the overall objectives of the Initiative organized into four program areas: Management, Genomics R&D Capacity, Research and Development, and Outreach. The key performance indicators under each of these are:

**Management** – Enhanced governance, coordination and partnerships.

**Genomics R&D Capacity** – Increase and training of Highly Qualified Personnel; advancements in state-of-the-art infrastructure; and increased participation in national and international genomics initiatives.

**Research and Development** – Access to and sharing of technology and scientific knowledge; application of research results to develop innovative, new or improved methods, products, processes or technologies.

**Outreach** – Increased awareness and understanding of genomics research results and applications.

An overview of the RMAF is provided in Appendix B, including the Logic Model and related tables of performance indicators.



## Links to Departmental Objectives and Program Activity Architecture

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Projects funded under the GRDI are focused on departmental mandates and government priorities, and are aligned with the strategies of their respective departments.

The Genomics and Health Initiative (GHI) is the largest horizontal R&D initiative of the National Research Council (NRC); through its multi-disciplinary approach and research excellence NRC-GHI is making significant contributions to Canadian R&D priorities in health (chronic diseases and agri-food), in energy (biofuels) and for the environment (environmental technologies and bioproducts). This is achieved through the funding of research programs that are aligned with key industrial sectors, and focused on the translation of scientific and technical knowledge into social and economic development. The initiative enables NRC to deliver on its mandate to translate S&T into value for Canada through partnerships with other government organizations, academia, and industry to provide an integrated approach to S&T initiatives.

Agriculture and Agri-Food Canada (AAFC) provides information, research and technology, programs and policies to support Canada's agriculture, agri-food and agri-based product sectors. The GRDI directly supports two of the department's Strategic Outcomes:

a competitive sector that proactively manages risk and an innovative sector. Funding from the GRDI has enabled AAFC to strengthen the Canadian Crop Genomics Initiative (CCGI) through additional investments in plant genomics and in the formation of multi-disciplinary teams across Canada. Funding from the GRDI has been used to support the advancement of technologies for 1) the development of sustainable food and feed supply from cereals, pulses and oilseeds, and 2) the introduction of crop platforms for the generation of industrial and biofuel products. The CCGI catalyzes the formation of integrated S&T teams within AAFC and in partnership with universities, the private sector, non-governmental organizations and highly regarded international genomic institutes.

The GRDI supports four Health Canada (HC) strategic outcomes: Strengthened Knowledge Base to Address Health and Health Care Priorities; Access to Safe and Effective Health Products and Food Information for Healthy Choices; Reduced Health and Environmental Risk from Products and Substances, and Safer Living and Working Environments. It also supports the strategic outcome of the Public Health Agency of Canada (PHAC) of Healthier Population by promoting health and preventing disease and injury. The contribution of GRDI at HC is to generate knowledge that is vital to the effective

regulation of health related products. The Departmental Framework for Biotechnology outlines its biotechnology-related roles and responsibilities including providing leadership in policy and regulatory development, informing and engaging the public, ensuring an international position for Canada, and applying the benefits of biotechnology to HC's mandate. Four themes guide research activities of the GRDI: generation, use and societal impacts of human genetic information; health and safety of biotechnology products; human genomic applications and impacts related to diagnostics and disease; and microbial genomic applications and impacts related to diagnostics and disease.

The Canadian Forest Service of Natural Resources Canada (NRCan) promotes the sustainable development of Canada's forests and the competitiveness of the Canadian forest sector. The GRDI has developed the foundation for contributing to NRCan's Strategic Outcome *Economic Competitiveness* and to the Program Activity *Innovation from Forests to Market*. It is positioned at the leading edge of unique technological platforms for tree and insect tissue culture, molecular diagnostics, population genetics, biological control products and functional genomics. Resulting from this foundation is a critical mass of data, infrastructure, and partnerships that is starting to deliver important practical applications.

Environment Canada (EC) carries out its genomics research through the Strategic Applications of Genomics in the Environment (STAGE) program. Under the aegis of this program, the Department has focused funding on projects that examine how genomics tools and methods can be used to support its policy, regulatory decision making, and enforcement mandates. More specifically, projects address the following departmental priorities: Risk Identification (e.g. knowledge on the effects of environmental contaminants on the biodiversity and function of microbial communities); Risk Assessment/Management (e.g. more accurate data for submission and knowledge for assisting regulatory decisions); Conservation Biology and Wildlife Management (e.g. genetic markers for conservation and protection decisions); and Improved Enforcement and Compliance (e.g. sample identification and wildlife forensics).

The National Aquatic Biotechnology and Genomics R&D Program of Fisheries and Oceans Canada (DFO) supports genomics research related to responsibilities for fishery management, monitoring fish habitat, sustaining fisheries and aquaculture, and protecting marine resources. Specific goals for genomics research within four DFO research centres across Canada were developed for aquatic ecosystems and organisms in alignment to the department's mandate and strategic objectives.

## Links to Federal Science and Technology (S&T) Strategy (2007)

The vision of the federal S&T strategy – *Mobilizing Science and Technology to Canada's Advantage* – is to build a sustainable, national competitive advantage that is based on S&T and the skilled workers whose aspirations, ambitions, and talents bring innovations to life. The achievement of this vision is based on the creation of three S&T advantages for Canada: entrepreneurial advantage, knowledge advantage, and people advantage. The strategic direction and research programs of the GRDI contribute to all three of these advantages and are well aligned with the strategy's principles of promoting world-class excellence, focusing on priorities, fostering collaborative relationships and enhancing accountability.

**Entrepreneurial Advantage** Advantage Research funded under GRDI supports economic development objectives through strong partnerships with academia

and the private sector, with a focus on providing solutions to national challenges in public health, agriculture, environmental sustainability, and natural resource management (forests and fisheries). For example, antibodies developed by the NRC to neutralize the tumour-promoting effects of a specific marker protein were licensed and are now being developed by a commercial collaborator; knowledge developed by AAFC on a wheat leaf rust resistance gene will contribute to further understanding of resistance mechanisms that will assist in breeding new rust resistant varieties; and genomics-based evidence generated by the CFS of NRCan facilitated the environmental safety assessment of a virus that specifically infects the balsam fir sawfly, leading to its registration as a biological control product, commercialization by a research "spin-off" company, and application to forests in western Newfoundland

to control large sawfly infestations. Scientists from PHAC have developed an innovative technology that will aid in the rapid, economical and affordable detection and identification of Salmonella. The aim is to advance the technology to the point where it can be easily transferred to diagnostic laboratories. Currently a collaboration agreement, as well as a confidential disclosure agreement, is in place with the Veterinary Laboratory Agency (VLA) in the United Kingdom in order to complete the optimization and validation of the array. Upon completion of the work, the product will be sold and distributed within Europe and North America through Identibac, a commercial company supported by the VLA.

Commercial applications that generate wealth for Canadians are enabled by effective regulatory approaches. The GRDI supports effective, up-to-date and efficient regulations by providing scientific knowledge used to set appropriate standards and to evaluate product safety. Examples include diagnostic tools for quarantine species; detailed characterization of new products (food, pharmaceuticals, medical devices, etc.) to allow their responsible introduction and ongoing monitoring; and forensic tools to monitor fish resources to meet certification standards and allow access to global markets.

**Knowledge Advantage** The strategic focus for GRDI research is to contribute solutions to many of the issues most important to Canadians – protecting the environment, improving human health, developing new

treatments for chronic and infectious diseases, enhancing public safety and security, and managing agricultural and natural resources in a way that is sustainable. For example, the GRDI is a driving force behind successful health outcomes for Canadians as it tackles research on issues such as developing new treatments for cancer, heart disease, and a vast range of other acute and chronic diseases; developing vaccines; and understanding how to limit the spread of diseases and potential pandemics. New drugs, nutraceuticals, and functional foods are the result of genomics-based research that improves the health of Canadians and generates wealth to support the economy.

**People Advantage** Programs funded under the GRDI are used to attract, train, and support highly skilled personnel including research scientists, visiting fellows, PhD students, technicians, and policy analysts, providing them access to world-class research infrastructure and networks.

Collaborative relationships are an important part of the GRDI to bring together the unique capabilities, interests, and resources of research partners and stakeholders. They are created among government-based science organizations, universities, industry, and other research institutes, both nationally and internationally, through the sharing of technology platforms and by collaborating in research areas that cut across traditional departmental sectors. Industry collaborators are important participants in all NRC-led research projects.

## Resources

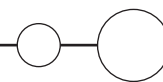
All departments have levered the GRDI with allocations from their A-base resources and from successful collaborations. **Table 2** provides an overview of resources in 2007-08, showing that leveraged funds represented more than two and a half times the GRDI

investments. Additional in kind leverage included the sharing of technology platforms, materials, and expertise with a variety of partners in research areas that cut across traditional departmental sectors.

**Table 2: GRDI and Leveraged Resources (\$'000)**

DEPARTMENT/AGENCY	GRDI \$	LEVERAGED \$	GRDI AND LEVERAGED \$
National Research Council Canada	6,000	17,351	23,351
Agriculture and Agri-Food Canada	6,000	7,200	13,200
Health Canada / Public Health Agency Canada	4,000	588	4,588
Natural Resources Canada	2,000	4,555	6,555
Environmental Canada	1,000	606	1,606
Fisheries and Oceans Canada	900	720	1,620
<b>TOTAL</b>	<b>19,900</b>	<b>31,020</b>	<b>50,920</b>

# Research Program Plans and Activities



Projects of the GRDI support innovation and related regulations and policies in the key Canadian economic sectors of forestry, agriculture, fisheries, health, and life sciences and related regulations and policies. Highlights of departmental plans and activities for 2007-08 are provided in the following sections. Additional details may be found in **Annex 1** of Appendix A.

The NRC Genomics and Health Initiative implemented recommendations received at a formal mid-term review in 2006-07 from the NRC-GHI Expert Panel and continued to focus its efforts on six research programs oriented towards diagnosing, treating and preventing human and animal disease, developing technologies for pathogen detection, and advancing new technologies for cardiac care and the production of commercially valuable agricultural crops.

The AAFC Canadian Crop Genomics Initiative focused on functional genomics of disease and insect resistance, tolerance to stress such as cold and drought, and enhanced quality attributes, in cereals (wheat and corn), oilseeds (*Brassica* and *Arabidopsis*) and legumes (soybeans).

The Departmental Framework for Biotechnology of HC outlines the Department's biotechnology-related roles and responsibilities including providing leadership in policy and regulation development, informing and engaging the public, ensuring an international position for Canada, and applying the benefits of biotechnology to HC's mandate.

From the perspective of PHAC, genomics of humans and microbes has the potential to radically alter the practice of *public health* in the future, with new approaches for disease surveillance, disease prevention and improvement of health status that can effectively counterbalance health care funding pressures.

The GRDI at NRCan continued to generate the scientific knowledge required for the development of tailored solutions to specific forestry issues, focusing on species and traits that are of economic importance. The following themes were supported: emerging environmental issues, to address forestry concerns such as monitoring and response to pests and pathogens; relationships between genomes, to study the genetic profiles and evolution of main pests, host defence mechanisms, host-pathogen interactions; and sustainable forestry and competitiveness, towards improvements of tree growth, wood quality characteristics and resistance to biotic and abiotic agents.

*Projects of the GRDI support innovation and related regulations and policies in the key Canadian economic sectors of forestry, agriculture, fisheries, health, and life sciences and related regulations and policies.*

Environment Canada has strengthened its internal capacity in eco-toxicogenomics and is using this capacity to explore how best to use genomics to fulfill EC mandates to protect Canadian aquatic systems, terrestrial systems, and wildlife from the harmful effects of existing and emerging environmental stressors (chemical, biological, and physical). Environment Canada investigators participate in broad national and international efforts in eco-toxicogenomics, and are acknowledged for their valuable expertise and scientific contributions.

The DFO continued to focus research on three themes: aquatic resource profiling, aquatic animal health, and aquatic ecosystem health. In addition, a strategic reorganization has positioned the Maritimes Region to increase access to genomics expertise and infrastructure, facilitating internal and external collaborations. Further, previously unfunded regions were engaged in order to develop an action plan to help strengthen genomics research across the department. This work will continue into the next phase.



# Performance

This 2007-08 Annual Performance Report is presented using the performance indicator categories outlined in the GRDI Results-based Management and Accountability Framework (RMAF), to outline progress on governance, coordination and science partnerships; research capacity; infrastructure; sharing of technology and scientific knowledge; public awareness of genomics; participation in national and international initiatives; and application of research results to develop innovative methods, products, processes or technologies. Consistent with previous years performance, participating departments have once again made excellent progress towards the objectives set for the GRDI.

## Management

Sound management is an important aspect of any government program. The six GRDI departments and agencies have established practices to define priorities effectively, support departmental coordination, and select projects to specifically address the identified priorities.

Collaborations are an important part of the GRDI as illustrated by **Tables 3** and **4**. **Table 3** shows GRDI interdepartmental collaborative activities during 2007-08.

**Table 4** shows the extent of collaborations with a wide variety of partners, for a total of close to 200 collaborations. These collaborations have allowed

the sharing of expertise and resources many projects involve researchers from Canadian and international research organizations and universities. For example, AAFC has made a significant contribution to the international *Brassica* genome sequencing effort, and success in *Brassica* genomics has prompted official UK-Canada cooperation on *Brassica* functional genomics, particularly in the area of seed oil accumulation.

Synergies were strengthened between federal scientists active in the GRDI and academic scientists active under large-scale programs financed by Genome Canada and regional genome centres. For example, NRC and AAFC researchers have collaborated extensively in a Genome Canada/Genome Prairie project *Enhancing Canola Through Genomics*. This joint research project led to the generation of important genomics resources including a set of more than 600,000 Expressed Sequence Tags (ESTs) – a unique DNA sequence resource representing genes expressed during canola seed development. These ESTs were publicly released to Genbank in June 2007, marking the single largest number of *Brassica napus* (canola) DNA sequences ever to be released to the global scientific community. Researchers from both organizations are also representing Canada's participation in a multi-national initiative to sequence the *Brassica rapa* genome. All these large-scale projects also involve industry partners and many international collaborators. Scientists of AAFC are playing a key role in the Genome Canada project *Designing Oilseeds for Tomorrow's Markets*, aiming to develop a canola genotype with improved meal quality for the valuable fish and animal feed market. Similarly, the NRC Canadian Forest Service (CFS) is a strong collaborator in the Genome Canada/ Genome Quebec project *Arborea II*, which identifies genes linked to the natural variability of growth and wood properties in a species of key economic importance, white spruce. The research is being led by researchers at Université Laval and 30% of the project team members are from the CFS. The CFS is also collaborating in a Genome BC/Genome Alberta project on mountain pine beetle system genomics. As well, PHAC scientists, in collaboration with researchers and provincial public health and agriculture colleagues, demonstrated that exposure to antimicrobials may cause *Salmonella* to become more virulent. Cooperative testing across Canada is ongoing to assess the potential consequences of this scientific finding.

**Table 3:**  
**Interdepartmental GRDI Collaborative Projects**

PARTNERS	RESEARCH AREA
AAFC – NRC	<i>Brassica</i> genomics technologies – biorenewable oil for food and fuel
AAFC – NRC	pre-commercial field – gene candidates for plant yield and vigor
NRC – EC	bioremediation of contaminated soils
DFO – NRC	genomics of finfish (e.g. salmon) and ground fish like cod and sole
NRCCan – AAFC NRCCan – AAFC	growth and adaptation in spruce functional genomics of insect viruses
PHAC – NRC	infectious disease and cancer treatment and diagnosis
NRCCan – NRC HC – PHAC	understanding tree defence response influenza viruses
EC – NRC	microbial environmental genomics
EC – DFO	shared equipment and laboratory space

**Table 4: Collaborations by Organization Type**

TYPE	NRC	AAFC	HC	NRCAN	EC	DFO	TOTALS
Universities (Canadian and International)	22	25	14	30	12	13	116
Other International Research Organizations	5	9	4	8	3	1	30
Other Canadian Research Institutions	6	–	3	9	3	1	22
Private Sector	5	8	3	2	1	3	22
Other Public Sector Organizations	–	5	3	–	1	–	9
<b>Total</b>	<b>38</b>	<b>47</b>	<b>27</b>	<b>49</b>	<b>20</b>	<b>18</b>	<b>199</b>

### Genomics R&D Capacity

As confirmed by the Formative Evaluation completed in 2006, most of the six government departments had limited capacity to carry out genomics research before the implementation of GRDI. Departments supported by GRDI funds now have the human resource capacity as well as the tools, equipment, infrastructure and networks required to undertake genomics R&D and participate in broader, high-impact programs established through formal and informal collaborations with Canadian and international organizations.

In 2007-08, the GRDI supported 82 post-doctoral fellows, 247 scientific and technical staff, 115 students (PhD, MSc, BSc, and Co-op), and 10 visiting scientists, for a total of 454 active research and technical personnel. **Annex 2** of Appendix A provides additional detail presented by department.

Departments continued to invest in core infrastructure facilities for DNA sequencing, proteomics and microarrays. Funding was also allocated towards the purchase, maintenance and upgrading of laboratory equipment such as real-time PCR equipment, spectrometers, electrophoresis and hybridization stations.

For example, HC used GRDI funding to purchase new computers and servers fully equipped with microarray/statistics software. Approximately \$285,000 was spent on a large retrovirus library. A laboratory for protein isolation was also established, with a workstation dedicated to proteomic analyses equipped with specialized software for the analysis of protein fingerprinting.

*Departments supported by GRDI funds now have the human resource capacity as well as the tools, equipment, infrastructure and networks required to undertake genomics R&D and participate in broader, high-impact programs established through formal and informal collaborations with Canadian and international organizations.*

### Research and Development

Research and Development is the central component of this initiative, together with activities surrounding the conduct of R&D, which are critical to ensuring relevance and impact, such as the transfer of knowledge, techniques and products to research partners and end-users, and the dissemination of research results. As part of the 2007-08 Report on Plans and Priorities, the participating departments established a collective set of planned results to:

- Develop commercially relevant advances in areas of genomics R&D related to human health (e.g. genetic testing, diagnostics, microbial genomic applications, treating and preventing human diseases such as cancer and cardiovascular disease, and pathogen detection);
- Realize crop value improvements in cereals, soybean and canola through improvements of adaptation to biotic and abiotic stresses (e.g. resistance to disease, tolerance to drought and cold) and productivity, and through studying seed development and metabolism (e.g. tailoring oil quality for biofuels and nutraceutical applications);

- Implement the sustainable management of aquatic resources through the use of genomics tools to: manage fishery openings; generate increased understanding of population genetics and structure; study behavioural, physiological and immunological responses to the environment; and manage aquatic animal diseases (e.g. develop vaccines for farmed fish);
- Position the Canadian regulatory system for health to enable innovation while minimizing the risks to Canadians through a focused genomics R&D program aimed at strengthening research in priority areas such as genetic information, biotechnology products, human genomics and microbial genomics, on human, animal and environmental health;
- Increase knowledge of forest generation and protection methods, and for addressing environmental impact considerations, through a focused genomics R&D effort on species and traits that are of economic importance to Canada; and
- Develop genome-science applications to support regulatory and enforcement activities in key areas such as environmental risk assessment and management; enforcement and compliance; pollution detection, monitoring and prevention; conservation biology and wildlife genetics; technology forecasting and assessment; and the responsible and sustainable development and use of bio-based products and industrial processes.

*An important goal of the GRDI is to ensure that federal research scientists remain influential as part of the world's major scientific players in the rapidly evolving field of genomics.*

A detailed account of the results achieved in each of these areas is provided in **Annex 3**, and shows that the GRDI has supported the development of vast amounts of new knowledge and innovative technologies targeted at improving human health, environmental and natural resource management, agriculture, and food safety. The **Application Highlights** section exemplifies some of the most notable applied results obtained in 2007-08.

An important goal of the GRDI is to ensure that federal research scientists remain influential as part of the world's major scientific players in the rapidly evolving field of genomics. This is achieved through scientific publications and presentations at national and international conferences and workshops, and participation in committees, boards and networks. The following enumerates direct R&D outputs, while **Annex 4** of Appendix A provides additional detail broken down by department/agency:

- 204 publications in refereed journals;
- 103 publications in conference proceedings;
- 164 invited presentations;
- 18 technical reports;
- 46 other publications;
- 180 presentations and posters at national and international conferences;
- 9 book chapters;
- 15 patent applications;
- 3 patents issued;
- 7 material transfer agreements;
- 18 formal collaborative agreements;
- 2 books edited;
- 2 genomics related databases;
- 8 standard operating procedures transferred; and
- numerous GenBank deposits (ex. *Brassica*, wheat, soybean sclerotinia pathogens, spruce budworm, baculoviruses).

### **Outreach**

While the previous three components are important to ensuring that the right research is done at the right time and that the research results are disseminated within the scientific community, it is also important for genomics to be well understood and accepted by Canadians. Direct and indirect public communications are therefore an important aspect of this initiative; however efforts in this area remained modest in 2007-08. Still, there were 11 media interviews, 4 press releases and several community presentations, demonstrations, tours, and participations in science fairs and in public school events. Additionally, departments maintain public websites, and have published pamphlets and brochures detailing genomics R&D results and achievements. Additional details broken down by department/agency are provided in **Annex 5** of Appendix A.

# Appendix A

## Supplemental Performance Details

### Annex 1 – GRDI Funded Projects by Department

#### National Research Council Canada

##### **Brassica Seed Development**

The Functional Genomics of Brassica Seed Development and Metabolism Program represents a comprehensive functional genomics dissection of canola (and related Brassica spp) ranging from embryogenesis through maturation and germination.

##### **Pathogen Detection**

This program is focused on developing new technologies that will facilitate rapid, cost effective biomolecular sensing for applications ranging from field devices to point-of-care analyses.

##### **Chronic Cardiovascular Disease**

This program is aimed at developing improved imaging and diagnostic methods to assess patient response to treatments, to assist in planning and guidance of surgery as well as aid in the effective triage of patients.

##### **Kinase Signalling Networks**

This research project seeks to evaluate the protein-protein interactions that link proteins in cell signalling systems as possible targets for small molecule therapeutics of human diseases.

##### **Aquatic Animal Disease Management**

This program is focused on developing targeted antigens and delivery systems for vaccine development against pathogens affecting Atlantic salmon.

##### **Personalized Medicine for Cancer**

The aim of this program is to discover gene/protein changes that either cause or provide signatures of cancer and to use them as targets for therapeutic molecules, and for imaging techniques to detect disease and track the efficacy of therapy.

#### Agriculture and Agri-Food Canada

##### **Biotic Stress**

Research in this area is ongoing to develop germplasm and varieties with resistance to economically important diseases and insect pests. Molecular biologists and

entomologists are examining and developing a molecular basis for both antibiotic and antixenotic approaches to insect and pathogen resistance.

##### **Abiotic Stress**

Parallel gene discovery programs in different systems are pursued to uncover novel and complementary avenues to engineering increased cold tolerance and increased frost resistance. Cold and heat tolerance and freezing resistance are important characteristics for almost all crops and are of crucial strategic importance to Canada as they have a significant bearing on yield potential and stability.

##### **Quality attributes in cereals (wheat, corn), oilseeds (Brassica/Arabidopsis) and legumes (soybeans)**

Research in this area focuses on important aspects of seed quality and aims to decipher the genes that control seed development, carbon partitioning, protein quality, oil quality, starch quality, and the accumulation of anti-nutritional compounds. Compounds of nutraceutical interest under study include phytosterols, anthramides and glucans.

#### Health Canada and the Public Health Agency

- Validation of toxicogenomics for use in regulatory toxicology
- Environmental health applications of toxico-genomics and proteomics. Identification of exposure and effect biomarkers for mutagenic carcinogens in complex environmental matrices
- Biological validations of instability in tandemly repeated genomic sequences in rodent and human cells for purposes of regulatory genotoxicity evaluations
- Application of the p53+/- transgenic mouse for alternative cancer bioassays: genomic characterization of tissues from mice exposed to genotoxic and non-genotoxic carcinogens
- Study of interferon-induced hepatic injury using genomic and proteomic approaches
- Biomarkers of exposure and effects of inhaled contaminants in atherosclerosis and asthma



- Biomarker discovery for diagnosis of prion disease
- Biotech 2005: a genetic “knock-down” approach to identify host cellular factors essential for infectious agent replication and pathogenesis
- Genomic approaches to provide molecular markers for Salmonella typing
- Immuno-informatics for epitope discovery in infectious pathogens: applications in identification of potential diagnostic markers and vaccine candidates

### **Natural Resources Canada**

- Nucleopolyhedrovirus functional and comparative genomics
- Functional genomics of *Choristoneura fumiferana* multicapsid nucleopolyhedro-viruses (CfMNPV): role of all the open reading frames in the infection process
- Transcriptomics analysis of insect molting
- Effects of the larval host on genomic variation and evolution of insect viruses: implications for pest control
- Molecular tools for studies on the ecology and phylogeny of microsporidia in forest defoliators
- A tree functional genomics platform for gene function discovery
- Genome-wide scan to reveal genes underlying growth productivity traits in white spruce (*Picea glauca*)
- Association mapping of wood characters in white spruce
- Fungal genomics for protection and conservation
- Interacting genomes
- Molecular and genetic characterization of conifer host-laminated root rot (*Phellinus* spp.) pathosystems
- Molecular analysis, elicitor activity, isolation of functional R genes and genetic engineering of white pine resistant to blister rust fungus

### **Environment Canada**

- Development and standardization of test methods using environmental genomics techniques
- Gene expression technologies – applications to wildlife toxicology
- Initiation of a QuantiGene Plex Assay for salmonid endocrine building on gene targets
- Genetic characterization of strains of *Pasteurella multocida* isolated from large scale avian cholera outbreaks across Canada
- Genetics of eastern Barrow's Goldeneye
- Phenotypic variation in polar bears

- Migration dynamics and population genetic structure of the loggerhead shrike
- Design and optimization of quantification protocols for improving the utility of DNA microarrays used in environmental effects monitoring
- Development and application of novel genomics-based techniques for the identification and quantification of microorganisms to assess the effectiveness of wastewater treatment systems
- Establishing molecular assessment techniques for emerging infectious diseases in native amphibians
- Eco-toxicogenomics of nanomaterials – Detection of genetically modified organisms and bacterial genes in aquatic ecosystems
- Validation of genomics tools for the prediction of environmental effects: response of fish to contaminated sediments
- Development and validation of a lobster eco-toxicogenomic array – correlation of gene expression profiles with traditional toxicological end-points for contaminant exposure
- DNA microarray fingerprinting of virulence and antibiotic resistance genes in *Escherichia coli*
- Ecological effects of genetically modified organisms and other biotech products at the genomic level

### **Fisheries and Oceans Canada**

- Phylogeography and pathogenomics of viral hemorrhagic septicemia virus (VHSV) and salmon anemia virus (ISAV) in Canada
- Heat-shock protein-combined vaccines: conception and efficacy
- Application and validation of metagenomics for monitoring aquatic ecosystem health
- Development and use of comparative molecular markers to assess levels and patterns of genetic diversity in winter skate (*Leucoraja ocellata*)
- DNA based mussel species identification and its application in a geographic survey of the species composition of seed sized mussels collected around Nova Scotia
- Preliminary investigations into the use of Single Nucleotide Polymorphism (SNP) variation to assign Northwest Atlantic cod to region of origin
- Expression profiling of Fraser River late run sockeye salmon: migration physiology uncovered using cDNA microarray technology
- Identifying conservation units among wild adadromous Atlantic salmon
- Sequence-level comparison of Atlantic and Pacific salmon growth hormone gene regions

# Appendix A

## Supplemental Performance Details

### Annex 2 – Highly Qualified Personnel (HQP) by Department

#### National Research Council Canada

*95 research and technical personnel were active under the initiative:*

- 22 PDF
- 39 technical officers
- 6 computer services personnel
- 22 research officers/research council officers
- 6 students

#### Agriculture and Agri-Food Canada

*176 research and technical personnel were active under the initiative:*

- 34 PDF
- 4 visiting scientists
- 63 university students (21 PhD, 19 MSc, 23 undergraduates)
- 75 scientific and technical staff (11 adjunct professors in 6 universities)

#### Health Canada and the Public Health Agency

*43 research and technical personnel were active under the initiative:*

- 13 Principal Investigators
- 4 PDF
- 11 indeterminate positions
- 10 university students (1 PhD, 2 MSc and 7 undergraduates)
- 5 technical positions

#### Natural Resources Canada

*84 research and technical personnel were active under the initiative:*

- 18 PDF
- 12 research scientists
- 28 biologists/technicians
- 20 university students (9 MSc and PhD, 11 undergraduates)
- 6 visiting scientists

#### Environment Canada

*35 research and technical personnel were active under the initiative:*

- 4 PDF
- 2 research professionals
- 2 research technicians
- 1 chemist
- 9 students (1 PhD, 1 MSc, 7 undergraduates)
- 17 research scientists

#### Fisheries and Oceans Canada

*21 research and technical personnel were active under the initiative:*

- 9 technical staff
- 7 students
- 5 research scientists

# Appendix A

## Supplemental Performance Details

### Annex 3 – Planned Results versus Achieved Results (2007-08)

#### Planned Result 1

*Develop commercially relevant advances in areas of genomics R&D related to human health (e.g. genetic testing, diagnostics, microbial genomic applications, treating and preventing human diseases such as cancer and cardiovascular disease, and pathogen detection)*

#### Achieved Result 1

Cancer research at the NRC is targeted at discovering gene/protein changes that either cause or provide signatures of cancer, and to use them as targets for therapeutic molecules and for imaging techniques that detect disease and track the efficacy of therapy. Researchers have discovered a new family of antibodies that can play a role in preventing tumour invasion by blocking the function of secreted clusterin, a glycoprotein associated with human cancers that play a role in cell survival or death. By inhibiting gene function in cancer cells, it is possible to enhance the effects and efficiency of cell reaction and sensitivity to chemotherapy and other drug mediated therapeutics. A Canadian biotech company, Alethia Biotherapeutics, entered into a licensing agreement with NRC in 2007-08 for the worldwide therapeutic and diagnostic rights to clusterin-specific antibodies.

Scientists at the NRC are working to develop portable and efficient "all-in-one" diagnostic devices to detect human pathogens. The objective of the research is to create low-cost diagnostic tools that can eventually be produced industrially for commercial applications – devices that will rapidly identify human pathogens and provide instant read-out results eliminating conventional lengthy lab procedures. In a first step towards this goal, in 2007-08 researchers developed a 'personal microarray spotter' – a powerful miniature device used to spot and analyze many protein samples simultaneously. With further development, personal microarray spotters have the potential to revolutionize genomic/proteomic research in the laboratory and play a larger role in how researchers and clinicians understand, diagnose and treat a vast array of diseases or pathogens – from pesky allergens to pathogens such as *Salmonella* and *E. coli*.

#### Planned Result 2

*Realize crop value improvements in cereals, soybean and canola through improvements of adaptation to biotic and abiotic stresses (e.g. resistance to disease, tolerance to drought and cold) and productivity, and through studying seed development and metabolism (e.g. tailoring oil quality for biofuels and nutraceutical applications)*

#### Achieved Result 2

The next big targets in wheat genomics and application to wheat breeding have been identified as the construction of wheat physical maps, sequencing of the wheat genome and the development of functional genomics tools. Scientists at AAFC have made world class advances in functional genomics which allows the development of new wheat breeding strategies for traits of economic importance such as yield or quality that are governed by many genes. In the past, the connection between the expression of an enormous number of genes at any one time and which of those genes controlled the appearance of a given trait has been unclear. Progress has been made in relating the expression of specific genes to the trait itself. This has been accomplished, for example, by studying the expression of the many genes during seed development and correlating specific genes to the appearance of specific trait(s). The approach was published in the high impact **Plant Biotechnology Journal** and is being applied by other laboratories worldwide. Furthermore, this approach has contributed to the elaboration of the wheat map where several wheat chromosomal locations have been identified to be important for the control of many other genes including those of economic importance. Also, thousands of new molecular markers have been identified and are being shared with breeders worldwide to test candidate genes and select useful molecular markers for wheat quality related traits such as protein content, dietary fibre, pre harvest sprouting and yield.

Wheat produces the largest farm gate value as well as acreage of all Canadian crops (25 million acres planted and over \$4 billion farm gate per year) and several established and potential diseases threaten the sustainability of wheat production in Canada. One disease, Fusarium Head Blight (FHB) has already caused cumulative losses of over \$1.5 billion at the Canadian farm gate and many fold more worldwide. In addition to reducing seed mass and quality, the fungus causing FHB contaminates grain with toxic metabolites that are a threat to human and animal health. Efforts in 2007-08 by AAFC researchers resulted in the development of a large collection of genes expressed by *Fusarium graminearum* in a range of growth conditions, and especially during host invasion. An international group of scientists from 21 different institutes representing 9 countries, where cereal production is of major economic importance, collaborated to sequence, annotate and compare two strains of this fungus. Contributing countries (and the number of institutions) included USA (11), Canada (2), Germany (2), Netherlands, Spain (1), Australia (1) France (1), Spain (1) and Ukraine (1). Scientists of AAFC contributed manual annotation to the genome sequence. The results were published in the prestigious scientific journal *Science* 317, 1400-1402, 2007. The completed genome of *Fusarium graminearum* identified distinct regions enriched for infection related genes. Recognition of these regions of the genome focuses the direction of future work toward those regions that may have the greatest potential in elucidating the dynamics of host pathogen interactions. Scientists of AAFC are also leading the way in isolating both resistance genes for the devastating canola pathogen blackleg and the corresponding avirulence factors from the causal fungus. This should lead to the rapid development of new resistant germplasm and potentially designer resistance genes. Genomics tools were also used to identify master switches (transcription factors) that could regulate suites of genes involved in disease protection. A master switch (GLK1) was identified at AAFC to protect wheat against FHB. As this gene regulates defense related pathways, it will also potentially protect other Canadian crops against diseases. A patent has been filed for the utilization of this invention.

The identification and functional characterization of plant genes involved in signalling mechanisms that render a host root susceptible to infection and root colonization by beneficial soil microorganisms consti-

tutes an important goal towards a reduction in the use of chemical fertilizers through the development of biofertilizers. During the last year AAFC legume scientists identified and genetically mapped several new chromosome regions responsible for this process. This will allow the unmasking of the underlying genes at the molecular level. Furthermore, as part of an international effort involving 6 research groups from 4 different countries (Denmark, Japan, Canada, and United Kingdom), AAFC scientists identified and functionally characterized two new genes that mediate invasion of roots by nitrogen fixing bacteria. The results were published in the top plant scientific journal **Plant Cell**. In the long term, this research should lead to the development of novel strategies for enhancement of plant productivity through selective engineering of associations of crop plants with beneficial, plant growth promoting, microorganisms, resulting in the development of custom made biofertilizers. This breakthrough could lead to the development of ecological and cost effective alternatives to certain industrial fertilizers, which could bring enormous environmental and financial benefits to Canada. Nitrogen makes up more than 80% of the earth's atmosphere and is essential to the growth of all living organisms. However, atmospheric nitrogen cannot be directly accessed by most plants or animals until it is incorporated into organic compounds by biological nitrogen fixation or other natural processes. Biological nitrogen fixation provides more than twice the amount of industrially-produced nitrogen to natural and agricultural ecosystems in a manner that is both sustainable and environmentally friendly. If the ability to host nitrogen fixing bacteria could be extended to even one lucrative crop, such as corn or rice, the results would constitute a second 'green revolution' with clear benefits to producers and the environment.

The soil borne pathogen *Phytophthora sojae* causes root rot and damping off of soybean. Race-cultivar compatibility between the pathogen and its host is controlled by discrete genes. Thus, *P. sojae* avirulence (*Avr*) genes can restrict the pathogen and determine which cultivars of soybean are resistant or susceptible to disease. In 2007-08 AAFC researchers identified at least three different *P. sojae* *Avr* genes; *Avr1a*, *Avr3a*, and *Avr3c*. The discovery of *Avr* genes will lead to a more rational approach to breeding, diagnostics, and cultivar deployment and help in the control of *P. sojae* in the field. It will also lead to a better mechanistic understanding of disease and how it may be managed.



Canola (*Brassica napus*) currently contributes over \$11 billion in economic activity to the Canadian economy. The value of canola and other related *Brassica* species is expected to grow due to the increasing demand for food, feed and bioproducts applications. The complete genome sequence of *Brassica* species, together with increasing insights into gene function can be applied to making major improvements in crop productivity and quality to meet the increased demand. Agriculture and Agri-Food Canada in collaboration with the NRC Plant Biotechnology Institute has already played a significant role in the sequencing of the first *Brassica* genome, *B. rapa*, by contributing 27% of the data for Phase I of this International Project. Scientists of AAFC are now working with national and international collaborators in Korea, China, United Kingdom and Australia to complete the genome sequence, which should be released in late 2009. The sequence data will represent a reference point and a major milestone in plant genetics, but more importantly will be a significant step towards understanding the molecular processes underlying seed composition, quality, yield, and resistance of plants, surpassing the presently available catalogues of genes.

A functional analysis of *Brassica* (e.g. canola) seed development and metabolic processes was undertaken with the goal of improving *Brassica* seed quality traits. In 2007-08 NRC researchers discovered a gene that can boost the productivity and resilience of canola; DNA sequences suggest that the gene, which produces a hydroxysteroid dehydrogenase (HSD) protein, is involved in steroid metabolism and has a profound impact on plant growth. Researchers over-expressed the gene to create "transgenic" plants that would produce higher levels of the HSD protein than found in unmodified plants. The experiment resulted in taller, stronger and more durable plants with increased seed production and an average yield of oil that exceeded control plants by roughly 23 percent. This discovery has the potential to help Canadian canola growers produce more oil for food applications, as well as increase oil production to meet the growing demand for biodiesel fuel.

### Planned Result 3

***Implement the sustainable management of aquatic resources through the use of genomics tools to: manage fishery openings; generate increased understanding of population genetics and structure; study behavioural, physiological and immunological responses to the environment; and manage aquatic animal diseases (e.g. develop vaccines for farmed fish)***

### Achieved Result 3

Research is being undertaken with support from industry and the province of Nova Scotia to efficiently and effectively identify genetic differences between two morphologically similar mussel species *Mytilus edulis* and *M. trossulus*, and determine the relative distribution of these species within Nova Scotia. Genetic markers have been developed and optimized for higher throughput analysis and for use in future selective breeding activities. Results indicate that there are very different species compositions at locations that are adjacent to each other, and have identified sites suitable for mussel seed collection for use in aquaculture in Nova Scotia, thereby helping to overcome the impacts from the restriction of movement of species from areas with aquatic invasive species.

In order to better manage fishery openings and understand the changing behaviour of fish stocks due to climate change and pollution, genomics tools including gene expression profiling are being used to determine physiological changes along the migration route to natal streams that are associated with early entry, a behavioural shift in late run Fraser River sockeye salmon. Results to date indicate that osmoregulatory readiness was not used to cue the timing of river entry but may be important to successful migration within the river. As well, biomarkers were identified that are associated with energy reserves, maturation processes, navigation strategies and cueing systems, osmoregulatory preparedness, and temperature response. A tremendous breadth of new knowledge on salmon migration physiology was gained. Such predictive biomarkers will be invaluable for the monitoring of relevant genes to enable pre-season prediction of migration behaviour and fish survival for fishery managers.

Infectious diseases present a significant economic burden to finfish aquaculture industries and there is concern that diseases may also negatively impact wild fish populations. Genomic approaches are being used to better understand the diversity of viral hemorrhagic

septicemia virus (VHSV) and to relate this diversity to host responses to infection, disease development, and recovery or resistance to clinical disease. Multiple isolations of VHSV from marine waters off the coast of New Brunswick, Nova Scotia and British Columbia have been genetically analyzed, and this information has been used to develop a database for use in rapid identification and analysis of isolates. Recently, VHSV has been detected in the Great Lakes region; this strain is most closely related to isolates from New Brunswick and Nova Scotia, suggesting introduction from an eastern reservoir. Research is continuing to better understand the genetic basis of virulence among strains identified in Canadian waters.

Several live attenuated vaccine candidates were tested by NRC to protect Atlantic salmon against a major pathogen (*Aeromonas salmonicida*). Four approaches (protein subunit vaccines, attenuated *A. salmonicida* strains, DNA vaccines and lipopolysaccharide conjugates) had shown notable protection of Atlantic salmon from *A. salmonicida* infection. The approaches were designed to allow the future development of multi-valent vaccines targeting more pathogens in a single injection and providing more effective protection. Four provisional patents stemming from these vaccine approaches were filed in May, 2007. Of particular interest was the observation that the host immune response to *A. salmonicida* infection is primarily a cellular response, suggesting that *A. salmonicida* might be a suitable vehicle for the delivery of viral antigens.

In 2007-08 novel vaccine types continued to be explored by DFO. Three different approaches are being targeted and based on the indirect but more powerful stimulation of the immune system via the activation of antigen presenting cells (APC) through heat-shock proteins (HSP)-antigen complexes. Atlantic cod and the pathogen nodavirus is the model for several reasons. Cod farming is nearing the commercial stage in eastern Canada, and is a promising substitute to an almost inexistent fishery. Nodavirus is a serious pathogen of concern for cod farming, with several outbreaks reported in juvenile fish in the past 4 years. The immune system of Atlantic cod seem to possess unique characteristics, although cods can be immunized, a specific immunoglobulin response cannot be detected, so it is believed that cellular and non-specific immune responses are likely to be more important for this species. HSP-peptide vaccines are considered excellent candidates as HSP-peptide complexes are potent stimulators of a variety of immune responses, but assays for fish vaccines have not yet been reported.

#### **Planned Result 4**

*Position the Canadian regulatory system for health to enable innovation while minimizing the risks to Canadians through a focused genomics R&D program aimed at strengthening research in priority areas such as genetic information, biotechnology products, human genomics and microbial genomics, on human, animal and environmental health*

#### **Achieved Result 4**

In 2007-08 genomics research within the Health Portfolio (HC and PHAC) continued to focus on the development and application of “omics” tools to reduce exposure to food borne pathogens. For example, PHAC developed a miniaturized tube microarray to identify the 100 *Salmonella* serotypes most frequently involved in human gastroenteritis. Each type of *Salmonella* is unique in its host range and epidemiology, and the determination of serotype is an important step in the characterization of clinical isolates. Currently available methods are complicated and expensive, causing delays that hinder the containment of outbreaks and increase their cost to society. Microbial genomic applications have provided some new and profound insights into the diversity and spread of extended-spectrum cephalosporin (ESC) resistance plasmids in *Salmonella*. Standardized protocols for the characterization of ESC resistance plasmids were developed for inter-laboratory comparisons/collaborations. A Database containing major restriction profiles from ESC resistance plasmids and other resistance plasmids from *Salmonella* has been setup to allow for continued surveillance and for comparison purposes with other laboratories. This rapid, economical and user-friendly platform for *Salmonella* serotyping represents a leading Canadian innovation allowing rapid responses to outbreaks, improving public health and saving costs, and presenting an opportunity for commercialization in Canada and internationally.

Health Portfolio projects continued to build on existing research focusing on environmental toxicogenomics. Toxicogenomics is the application of genetic methods to the study of toxicology. A new multiplex immunoassay based on liquid protein arrays was developed. This novel approach provides an improvement over existing technologies for more rapid, high-throughput antibody-based detection of selected proteins. This is now being

deployed for proteomic characterization of allergen immunoreactivity in our experimental models (mice and rats). Current research is also providing insight into the cellular changes associated with exposure to different classes of contaminants in food and the environment. Scientists developed a stable mouse cell line that expresses a genetically engineered fluorescent protein gene designed to report mutations in repeat DNA segments. Several types of toxins and environmental contaminants were examined, using microarray technology, in a “genome-wide” test for induced DNA methylation changes. The results from 2007-08 have provided insights specific to gene expression changes, driven by exposure to toxic substances. For example, scientists completed the analysis of the proteome of human lung epithelial cells after exposure to a number of urban particles, diesel particles, and nanoparticles to reveal protein responses that provide insights into the mechanisms of toxicity and resulted in the development of a new ‘shot-gun’ proteomics method for screening of protein/peptide biomarkers in rat plasma. Another research project was successful in characterizing cardio-pulmonary responses to cigarette smoke in the laboratory, which resulted in the identification of potential candidate biomarkers to predict the health outcome of cigarette smoking.

In 2007-08 research continued in the generation of pharmacogenomic and biotherapeutics data focusing on the quality and potential health risks of novel therapies. For example, improved methodologies have been developed to analyze the potency and quality of the biotherapeutic interferon that are now being validated against other currently-used methods in terms of accuracy, simplicity, and reproducibility for the improved quality control of interferon assays. Health Canada increasingly recognizes the significant role that such data will play in future drug approvals in Canada. Results revealed differential patterns of host responses following various regimes of biotherapies, pointing to the possible identification of specific biomarkers linked to adverse reactions. This increased understanding helps position HC to meet the regulatory challenges of analyzing such data for sound, science-based regulatory decisions.

Federal scientists, together with local, national and international collaborators, continued their focus on public health genomics research. Health Canada has lead a collaborative project including PHAC, the World Health Organization and the Chinese Food and Drug Administration in the development of a robust method to quantify a specific sequence of hemagglutinin, the primary antigen in influenza viruses which remains highly conserved in a wide variety of flu strains, using antibodies obtained through original bioengineering approaches. This method is now patented and will allow for the efficient release of influenza vaccines for annual vaccination campaigns and for a rapid response in the case of a potential pandemic. Scientists also identified novel epitopes of a protein associated with protection from HIV-1 infection that will contribute to the development of HIV-1 vaccines. They have also developed enhanced capability to produce monoclonal antibodies to pathogenic targets including *Chlamydia* and *Neisseria* Spp.

Research completed in 2007-08 at PHAC led to the development of a large-scale RNA interference library targeting most of the human genome for its ability to identify host cellular genes that have a role in supporting virus and transmissible spongiform encephalopathy (prion) pathogenesis. Prion diseases of humans include classic Creutzfeldt-Jakob disease. Further funding from national and international partners and commercial partners was secured to continue towards the development of a commercially available pre-clinical test. These results are likely to prove effective in the rapid detection, surveillance and risk assessment of prion contamination, and other subtypes of organisms with the greatest public health risk.

Health Canada used genomics to analyze the bacterial composition of the large intestine and its response to fermentable dietary material, thus forming the basis for understanding the role of prebiotics and probiotics in foods. This information has helped shape HC's policies on probiotics, as well as policy decisions on the addition and labelling of this material in food products, thus providing Canadian's with choices on the foods they consume.

## Planned Result 5

*Increase knowledge of forest generation and protection methods, and for addressing environmental impact considerations, through a focused genomics R&D effort on species and traits that are of economic importance to Canada*

## Achieved Result 5

A genome scan by NRCan scientists in 2007-08 revealed that gene islands underlying growth and adaptation in spruce allowed the rapid selection of candidate gene to support linkage and association mapping experiments. Budset related genes were the target of newly synthesized libraries and ongoing expression profiling experiments. The NRCan Canadian Forest Service (CFS) developed a Single Nucleotide Polymorphism discovery Laboratory Information Management System and Database to track family members, expression data, PCR primers, amplification success and resequencing efforts. A composite map for black spruce was constructed as well as a white spruce consensus genetic map. Major quantitative trait loci were identified for the control of bud set and annual height increment in white spruce. In collaboration with Arborea II, a large-scale forest genomics project funded by Genome Canada and led from U. Laval, several hundred candidate genes have been identified for wood formation in white spruce. In collaboration with Treenomix, the other large-scale forest genomics project funded by Genome Canada and led from UBC, the CFS was able to localize the expression and induction profile of defence related genes, leading to improved understanding of insect resistance mechanisms in spruce and poplar. Recent progress in 2007-08 also demonstrated that a previously identified candidate gene in white pine is an important factor for plant defence response against pathogen invasion as well as for plant development. The CFS identified Douglas-fir disease resistance genes.

In 2007-08 the CFS made significant advances in the development of DNA diagnostic and monitoring tools for the early identification and tracking of pathogens. The Canadian Food Inspection Agency (CFIA) and the United States Department of Agriculture Animal and Plant Health Inspection service (USDA-APHIS) have adopted operationally the DNA-based diagnostic assays developed for sudden oak death by the CFS for their survey, certification, and quarantine applications. CFS

researchers working in collaboration with the Joint Genome Institute – Department of Energy (US) have completely sequenced the first forest pathogen, the poplar rust. Also, the first fungal plant pathogen genome to be sequenced in Canada, the fungal associate of the Mountain Pine Beetle, was completed at the Genome Science Center in Vancouver, a collaborative effort between Genome BC, Genome Alberta and CFS – Laurentian Forestry Centre. The CFS is currently generating large databases to identify genes that are involved in important disease processes (pathogenicity, infection, toxin production, host defence compound detoxification, and host recognition) for use in diagnostic tools.

The interaction between viruses and the natural host is a culmination of co-evolutionary events that lead to successful viral infection and the survival of the host. CFS work in this area in 2007-08 has demonstrated the dynamic relationship existing in any given populations of insect viruses and their host. Microarray studies have shown precise gene expression profiles following infection. The CFS also found through these studies that certain viruses produce proteins that have a down regulating effect on host genes involved in the immunity of larvae to parasites. This is a promising avenue to generate effective environmentally safe control agents against Lepidoptera and pest beetles such as the mountain pine beetle. The CFS fully sequenced and annotated the genome of the whitemarked tussock moth nucleopolyhedrovirus. The sequencing of viral genomes has resulted in a proposal for a new classification of the family Baculoviridae. This work was a significant contribution to the state of the art understanding of the evolution of baculoviruses and their adaptation to their insect hosts via the identification of most genes and open reading frames (ORFs) and understanding of the function of a majority of the identified genes. The CFS developed molecular tools for the detection of microsporidia, a group of unicellular insect pathogens, in outbreak populations of forest defoliators. In addition to the creation of baseline data on inter-relatedness, ecology and host specificity, these molecular tools were used to track the prevalence of microsporidia during an outbreak cycle of the jack pine budworm and eastern spruce budworm to elucidate their role in outbreak dynamics and study their transmission in insect populations.



## **Planned Result 6**

*Develop genome-science applications to support regulatory and enforcement activities in key areas such as environmental risk assessment and management; enforcement and compliance; pollution detection, monitoring and prevention; conservation biology and wildlife genetics; technology forecasting and assessment; and the responsible and sustainable development and use of bio-based products and industrial processes*

## **Achieved Result 6**

Environmental genomics approaches were used to:

- (1) investigate molecular-level effects of environmental contaminants on wild species to improve environmental risk assessment/ monitoring;
- (2) conduct molecular characterization of communities of microbes in contaminated soil so as to enhance bioremediation;
- (3) detect pathogenic micro-organisms in wastewater so as to assess the effectiveness of sewage treatment;
- (4) Improve decision making regarding management and conservation of several species of concern (e.g. polar bears; various bird populations);
- (5) detect the presence of genetically modified organisms (GMOs) and bacterial genes in aquatic ecosystems;
- (6) determine the ecological effects of GMOs and other biotechnology products at the genomic level.

In 2007-08 investments continued in environmental genomics foresight, knowledge development, instrumentation, infrastructure, and outreach (e.g. periodic comparative analysis of international environmental genomics activities via bilateral exchanges with US EPA). Environment Canada is also working closely with the Organization for Economic Co-operation and Development (OECD) and the International Programme on Chemical Safety (IPCS) of the World Health Organization (WHO) in developing strategies and work plans on several fronts to lead and co-ordinate international efforts to attempt to see how toxicogenomic methods and approaches might be applied within a regulatory context. Strengthening of partnerships and joint projects between federal departments continues (i.e. Environment Canada and Fisheries and Oceans Canada).

The methods developed for detecting biotechnology products formed the basis of a new provincial monitoring program (Quebec environment and sustainability); microarray technology was used to analyze microbial community compositions; toxicogenomic methods were applied to aquatic systems (marine and fresh-water) using relevant Canadian indicator species (fish, daphnids, amphibians). These results are used by Environment Canada's regulatory and enforcement branches to evaluate environmental microbial contamination, and by the City of Hamilton for the management of recreational waters.

# Appendix A

## Supplemental Performance Details

### Annex 4 – R&D Outputs by Department

#### National Research Council Canada

- 57 publications in referred journals
- 53 publications in refereed conference proceedings
- 76 invited presentations
- 6 technical reports
- 35 other publications
- 12 participations in national conferences / workshops
- 48 participations in international conferences / workshops
- 1 genomics related database
- 12 patent applications
- 1 patents issued
- 5 material transfer agreements
- 10 formal collaborative agreements

#### Agriculture and Agri-Food Canada

- 41 publications in refereed journals
- 31 invited presentations (of which 19 international)
- 64 posters
- 2 book chapters
- 2 patent applications, 1 US patent issued
- 72 papers reviewed by scientists for national and international journals
- 18 peer review panels with GRDI scientist membership
- 11 scientists holding editorial posts for national and international journals
- Numerous GenBank deposits (wheat, *Brassica*, soybean sclerotinia pathogens)

#### Health Canada and the Public Health Agency

- 40 publications in refereed journals
- 70 presentations, of which 18 were invited
- 1 book chapter
- 2 books edited
- 3 technical reports
- 1 patent application filed
- 2 material transfer agreements

#### Natural Resources Canada

- 42 publications in referred journals
- 45 publications in conference proceedings
- 17 invited presentations
- 1 technical report
- 6 book chapters
- 41 national conference presentations and posters
- 23 international conference presentations and posters
- 1 US patent issued
- Numerous GenBank deposits (spruce budworm, baculoviruses)

#### Environment Canada

- 16 publications in refereed journals
- 5 publications in refereed conference proceedings
- 17 invited presentations
- 6 technical reports
- 9 other publications
- Participants in 2 National Networks
- Participants in 2 International Committees
- 8 formal collaborative agreements
- 8 standard operating procedures transferred

#### Fisheries and Oceans Canada

- 8 publications in refereed journals
- 2 other publications
- 2 technical reports
- 5 invited presentations
- 4 participations in national committees
- 1 new database developed

# Appendix A Supplemental Performance Details

## Annex 5 – Outreach by Department

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### **National Research Council Canada**

- 2 media interviews
- 1 press release
- 2 websites (1 internal and 1 external)
- Several community presentations and tours conducted at GRDI participating institutes across Canada (Partners in Education, Discovery Day, Science Fairs)
- brochures were developed and made available at conferences
- 1 award: Dr. Alex Ko – Associate Researcher of the Year (2007-08) by the Board of Directors, National Optics Institute

### **Agriculture and Agri-Food Canada**

- 5 radio interviews and 3 print media stories
- 1 press release
- 2 fact sheets and related databases
- Demonstrations to the general public through open houses
- Presentations in public schools
- Participations in science fairs

### **Health Canada and the Public Health Agency**

- Increased the internal and external awareness and understanding of genomics research results and applications
- Detailed research results and achievements at intergovernmental conferences

### **Natural Resources Canada**

- 1 media interview
- 6 websites
- 1 award: Dr. Lucarotti received the 2007 New Brunswick Bio-Sciences Achievement Award. His work was recognized by BioAtlantech on behalf of the New Brunswick bioscience industries

### **Fisheries and Oceans Canada**

- 2 press releases
- 2 tours

## Appendix B

# Genomics R&D Initiative: RMAF Overview

In fulfillment of the requirements and guidelines of the Treasury Board Secretariat, a Results-based Management and Accountability Framework (RMAF) has been developed for the interdepartmental GRDI. The RMAF formalizes the commitment of the six departments involved in the Initiative regarding common measurement and accountability requirements.

A logic model has been developed (**Figure 1**) that reflects the overall objectives of the Initiative, recognizing that there are significant differences in particular needs and priorities of each department. The key objective of the GRDI is to sustain intramural genomics research in support of departmental mandates and key federal public policy objectives in areas of national interest (human health, agriculture and food safety, environment and natural resources management), to strengthen innovation, promote global competitiveness, and ensure sustainability for the benefit of all Canadians. Key results are related to four important program areas:

**Management** – While good management is an important aspect of any government programming, it is particularly important to recognize for this initiative because of the number of players: there are six departments and agencies involved and it is important that the practices in place support effective departmental and interdepartmental coordination. It is also critical that departmental and initiative priorities be well defined so that the projects are selected to ensure that government-wide priorities for genomics research information are addressed. Without this, the genomics research results may inadequately support regulations, policies and other types of decisions.

**Capacity Building** – Capacity building was the focus of the earlier phases of this initiative and it is critical that this capacity continue to be maintained and expanded. Without the hiring of new of highly qualified personnel (HQP) and training of existing personnel, the federal labs may lose some of their capacity and no longer be able to undertake the type of research projects required to ensure the success of the initiative as well as be credible participants in genomics research and applications. It is also critical that the existing infrastructure be maintained and that state-of-the-art

infrastructure be acquired to ensure that federal labs can continue to play their role in genomics research to inform regulations, policies and other decisions.

**Research and Development** – Research and development is the central component of this initiative. All activities surrounding the actual conduct of R&D, the transfer of the technologies developed, and the dissemination of the research results and scientific knowledge, are critical to ensuring progress towards all outcomes and ensuing impacts.

**Outreach (communications)** – While the previous three components are important to ensuring that the right research is done at the right time and that the research results are disseminated to the scientific community, it is also important for genomics to be well understood and accepted by Canadians. Direct and indirect public communications are therefore an important aspect of this initiative.

### Performance Measurement Plan

**Table 5** outlines the performance indicators, sources and responsibility for the outcomes outlined in the logic model presented in **Figure 1**. Information outlined in this table will be collected and reported annually.

**Table 6** outlines the performance indicators, sources and responsibility for the outcomes outlined in the logic model which should be examined at the time of a future impact evaluation. While information in this table may be collected annually, it will be analyzed and reported upon at the time of the impact evaluation.

Individual departments may also report on their individual progress in their Departmental Performance Report and use the information to adapt their programming and priorities.

**Tables 5 and 6** therefore outline specific data that needs to be collected by all departments, where appropriate. While some of the data will only be collected and analyzed at the time of the impact evaluation, the tables outline the following ongoing departmental requirements:

**Interdepartmental information** – Departments must maintain a record of all minutes of meetings, decision records, planning documents, etc. of an interdepartmental nature that has affected the way in which the initiative has been implemented in their own departments.

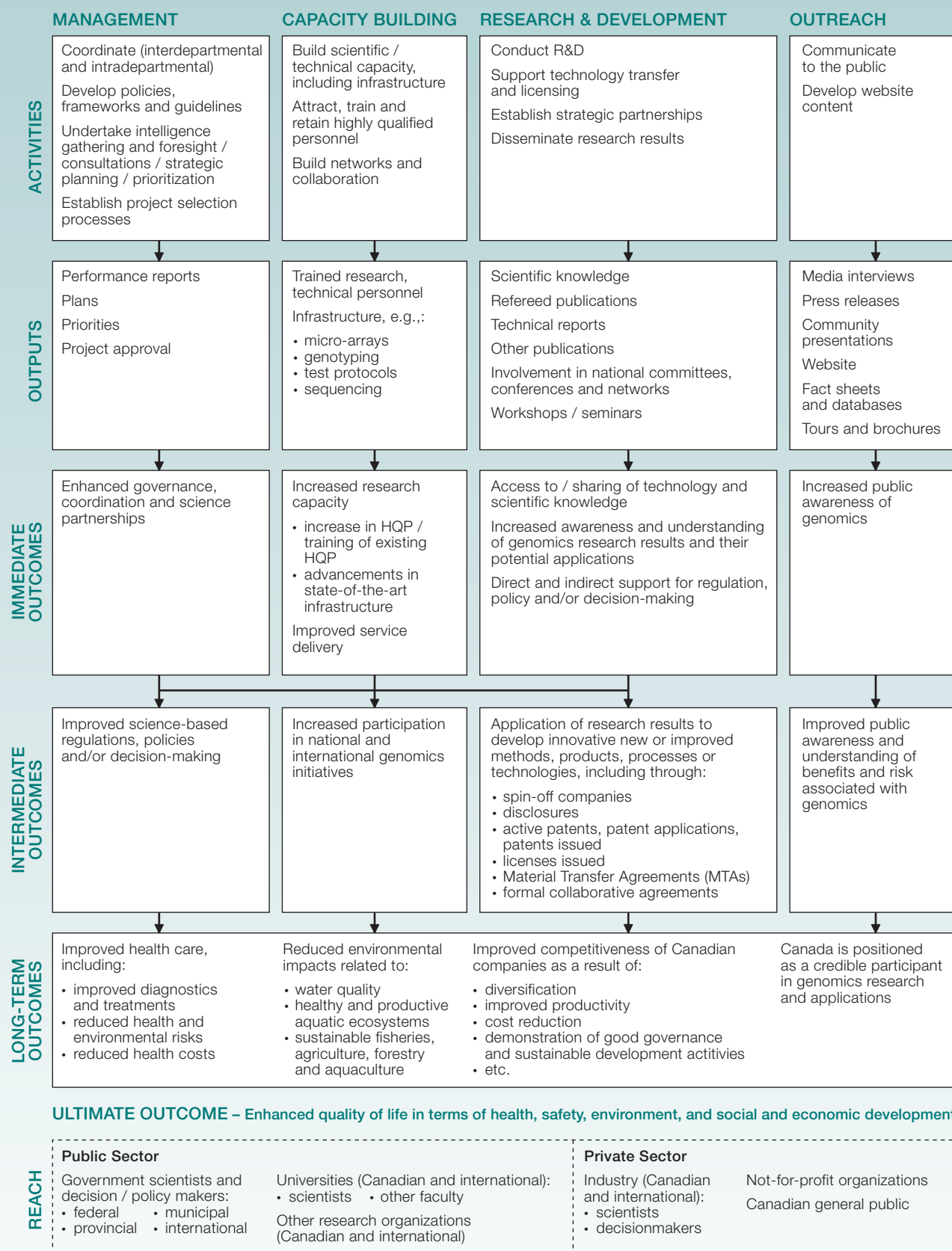
**Departmental information** – Departments also need to maintain a record of internal information that has affected the way in which the initiative has been implemented in their department. This includes program-level funding information (A-base and B-base funding), human resource information (hiring, training), non-project specific participation in national and international committees, conferences and networks, and website statistics.

**Project-specific information** – This includes the following information on projects:

- project applications (proposals, peer review assessments, etc.);
- projects approved (title, scope, funding level, description, objectives, lead scientist, team members);
- interdepartmental projects (title, scope, funding level, number of departments, description, objectives, lead scientist, team members);
- partners, collaborators on projects (names, type, financial contribution, in-kind contribution, role);
- regulators, policy makers, others accessing research results (names, titles, contact information);
- use of project funds (budgets including overhead charges or corporate taxes);
- infrastructure projects (types, funding level, % of total);
- # of papers in refereed journals (names of journals);
- # of papers in refereed conference proceedings;
- # of invited presentations;
- # of technical reports;
- # of book chapters;
- # of other publications;
- # and type of participation in national and international committees, conferences and networks related to projects;
- # and type of genomics related databases, libraries, etc. resulting from projects;
- application of research results and technology transferred;
- new products, tools, processes developed;
- spin-off companies (#, types, names, contact information);
- # of disclosures;
- # of active patents, patent applications, patents issued;
- # of licenses issued;
- # of material transfer agreements (MTAs);
- # of formal collaborative agreements; and
- # of standard operating protocols.



**Figure 1 – Logic Model for the Interdepartmental Genomics R&D Initiative**



**Table 5: Annual Performance Measurement Strategy**

AREA	ONGOING INDICATORS	SOURCES	RESPONSIBILITY
<b>IMMEDIATE OUTCOMES</b>			
Enhanced governance, coordination and science partnerships	# of interdepartmental research initiatives (table summarizing initiative, scope, \$, # of departments involved, description)	Project information	Departments
	# of partnerships / collaborations on projects by type, e.g.: <ul style="list-style-type: none"> <li>• OGDs</li> <li>• universities</li> <li>• international organizations</li> <li>• private sector</li> <li>• Genome Canada</li> <li>• etc.</li> </ul>	Project information	Departments
	Internal \$ leveraged: A-base and B-base funding	Departmental records	Departments
	Other funding and in-kind contributions by type (complementary to previous information on collaborations), e.g.: <ul style="list-style-type: none"> <li>• OGDs</li> <li>• universities</li> <li>• international organizations</li> <li>• private sector</li> <li>• Genome Canada</li> <li>• etc.</li> </ul>	Project information	Departments
Increased research capacity: <ul style="list-style-type: none"> <li>• Increase in HQP / training of existing HQP</li> </ul>	# and type of new research personnel: <ul style="list-style-type: none"> <li>• permanent and temporary (PDFs, students)</li> <li>• scientific and technical support</li> </ul>	Departmental records	Departments
	\$ and % of allocation to training and related HQP activity	Departmental records	Departments
	# of existing staff trained (genomics related)	Departmental records	Departments
	# of existing departmental staff working on Genomics R&D funded projects (increasing expertise by doing research)	Departmental records	Departments
• advancements in state-of-the-art infrastructure	Type of infrastructure: <ul style="list-style-type: none"> <li>• acquired</li> <li>• adapted</li> <li>• upgraded</li> <li>• maintained</li> </ul>	Project reports	Departments
	\$ and % of allocation to infrastructure	Departmental records	Departments
Access to / sharing of technology and scientific knowledge	# of papers in refereed journals (hard copy / electronic) <ul style="list-style-type: none"> <li>• information about journals available on request</li> </ul>	Project reports	Departments
	# of papers in refereed conference proceedings	Project reports	Departments
	# of invited presentations	Project reports	Departments
	# of technical reports	Project reports	Departments
	# of book chapters	Project reports	Departments
	# of other publications	Project reports	Departments
	# and type of participation in national / international committees, conferences and networks	Project reports Departmental records	Departments
	# and type of genomics related databases, libraries, etc.	Project reports	Departments
Public awareness of genomics	Web presence / # website hits / other website statistics	Analysis of website statistics	Departments

**Table 5: Annual Performance Measurement Strategy**

AREA	ONGOING INDICATORS	SOURCES	RESPONSIBILITY
<b>INTERMEDIATE OUTCOMES</b>			
Increased participation in national and international genomics initiatives	Extent to which scientists in departments participate in other projects <ul style="list-style-type: none"> <li>• national vs international</li> <li>• role on projects</li> <li>• leveraging</li> <li>• # of partners</li> <li>• OGDs vs universities vs private sector vs Genome Canada vs others</li> <li>• etc.</li> </ul>	Project information	Departments
	Other types of participation in national and international genomics initiatives <ul style="list-style-type: none"> <li>• number of initiatives</li> <li>• types of initiatives</li> <li>• role of departments / scientists</li> </ul>	Departmental records	Departments
Application of research results to develop innovative new or improved methods, products, processes or technologies, including through: <ul style="list-style-type: none"> <li>• spin-off companies</li> <li>• disclosures</li> <li>• active patents, patent applications, patents issues</li> <li>• licenses issued</li> <li>• Material Transfer Agreements (MTAs)</li> <li>• formal collaborative agreements</li> </ul>	Description of application of research results (internal and external) and / or technology transferred	Departmental records	Departments
	# and types of spin-off companies	Project reports	Departments
	# of disclosures	Project reports	Departments
	# of active patents, patent applications, patents issued	Project reports	Departments
	# of licenses issued	Project reports	Departments
	# of MTAs	Project reports	Departments
	# of formal collaborative agreements / # of standard operating protocols	Project reports	Departments

**Table 6: Impact Evaluation Performance Measurement Strategy Requirements**

AREA	EVALUATION INDICATORS	SOURCES	RESPONSIBILITY
<b>IMMEDIATE OUTCOMES</b>			
Enhanced governance, coordination and science partnerships	Evidence of coordinated planning (interdepartmental and intra-departmental), priority setting and management approaches (e.g., Genomics ADM Committee, Genomics R&D Working Group, linkages to CBS Fund and CRSB)	Minutes of meetings, decision records, planning documents, etc.	Departments and Genomics R&D Working Group
	# of interdepartmental research initiatives (table summarizing initiative, scope, \$, # of departments involved, description)	Project information	Evaluators based on departmental information
	# of partnerships / collaborations on projects by type, e.g.: <ul style="list-style-type: none"> <li>• OGDs</li> <li>• universities</li> <li>• international organizations</li> <li>• private sector</li> <li>• Genome Canada.</li> </ul>	Project information	Evaluators based on departmental information
	Internal \$ leveraged: A-base and B-base funding	Departmental records	Evaluators based on dept information
	Utilization of funds for intended purposes	Project information	Evaluators based on dept information
	Other funding and in-kind contributions by type (complementary to previous information on collaborations), e.g.: <ul style="list-style-type: none"> <li>• OGDs</li> <li>• universities</li> <li>• international organizations</li> <li>• private sector</li> <li>• Genome Canada.</li> </ul>	Project information	Evaluators based on departmental information
Increased awareness and understanding of genomics research results and their potential applications	Extent to which projects have addressed key genomics information needs within the departments	Comparison of project objectives to dept priorities; interviews with departmental managers	Evaluators based on departmental information
	Extent to which regulators, policy makers, decision-makers are aware of projects, their results and their potential applications <ul style="list-style-type: none"> <li>• within departments</li> <li>• in other departments</li> <li>• in other levels of government</li> <li>• in other organizations</li> </ul>	Interviews with regulators, policy makers, other managers and others	Evaluators based on departmental information
Direct and indirect support for regulation, policy and / or decision-making	Extent to which scientific evidence related to genomics is available and used in the development of regulations and policies as well as in other types of decisions <ul style="list-style-type: none"> <li>• within departments</li> <li>• in other departments</li> <li>• in other levels of government</li> </ul>	Interviews with regulators, policy makers and other managers, review of decision records, discussion documents, White Papers.	Evaluators based on departmental information
Public awareness of genomics	Level of public awareness of genomics	Survey of general public	Evaluators
	Web presence / # website hits / other website statistics	Analysis of website statistics	Evaluators based on dept information

**Table 6: Impact Evaluation Performance Measurement Strategy Requirements**

AREA	EVALUATION INDICATORS	SOURCES	RESPONSIBILITY
<b>INTERMEDIATE OUTCOMES</b>			
Improved science-based regulations, policies and / or decision-making	Evidence of contribution of scientific evidence to regulatory, enforcement, environmental assessment, public health and policy discussions and decisions <ul style="list-style-type: none"> <li>• within departments</li> <li>• in other departments</li> <li>• in other levels of government</li> </ul>	Interviews with regulators, policy makers and other managers, review of discussion documents, White Papers.	Evaluators based on departmental information
Increased participation in national and international genomics initiatives	Extent to which scientists in departments participate in other projects <ul style="list-style-type: none"> <li>• national vs international</li> <li>• role on projects</li> <li>• leveraging</li> <li>• # of partners</li> <li>• OGDs vs universities vs private sector vs GC vs others.</li> </ul>	Project information, interviews with scientists and partners	Evaluators based on departmental information
	Other types of participation in national and international genomics initiatives <ul style="list-style-type: none"> <li>• number and types of initiatives</li> <li>• role of departments / scientists</li> </ul>	Dept records, interviews with dept reps / reps of other initiatives	Evaluators based on departmental information
Application of research results to develop innovative new or improved methods, products, processes and technologies through: <ul style="list-style-type: none"> <li>• spin-off companies</li> <li>• disclosures</li> <li>• active patents, patent applications,</li> <li>• licenses issued</li> <li>• Material Transfer Agreements</li> <li>• formal collaborative agreements</li> </ul>	Description of application of research results (internal and external) and / or technology transferred	Departmental records	Evaluators based on departmental information
	# and type of products, tools and processes developed due to application of research results; description of use	Departmental records, interviews with recipient organizations	Evaluators based on departmental information
	# and types of citations	Citation analysis	Evaluators based on departmental information
Public understanding of genomics as an important contributor to their quality of life	Change in the level of public understanding	Survey of general public	Evaluators
	Change in media reporting	Content analysis of newspapers, other publications	Evaluators



**Table 6: Impact Evaluation Performance Measurement Strategy Requirements**

AREA	EVALUATION INDICATORS	SOURCES	RESPONSIBILITY
<b>LONG-TERM OUTCOMES</b>			
Improved health care, including: <ul style="list-style-type: none"> <li>• improved diagnostics and treatments</li> <li>• reduced health and environmental risks</li> <li>• reduced health costs</li> </ul>	Extent to which research results are used for diagnostics, treatments, prevention, etc.	Case studies, interviews	Evaluators based on departmental information
	Specific health care impacts (refer to Departmental RMAFs for specific indicators)	Case studies, analysis of secondary data on health care	Evaluators
Reduced environmental impacts related to: <ul style="list-style-type: none"> <li>• water quality</li> <li>• healthy and productive aquatic ecosystems</li> <li>• sustainable fisheries, agriculture, forestry and aquaculture</li> </ul>	Extent to which research results are used to refine environmental regulations and improve pollution detection, monitoring, and enforcement activities	Case studies, interviews	Evaluators based on departmental information
	Specific environmental impacts (refer to Departmental RMAFs for specific indicators)	Case studies, analysis of secondary data on environment	Evaluators
Improved competitiveness of Canadian companies as a result of: <ul style="list-style-type: none"> <li>• diversification</li> <li>• improved productivity</li> <li>• cost reduction</li> <li>• demonstration of good governance and sustainable development</li> </ul>	Extent to which research results are used by Canadian companies	Case studies, interviews	Evaluators based on departmental information
	Performance of companies using research results vs others in that sector (refer to Departmental RMAFs for specific indicators)	Case studies, analysis of secondary data	Evaluators
	Improved performance of specific sectors affected by research results	Case studies, analysis of secondary data	Evaluators
Canada is positioned as a credible participant in genomics research and applications	Level of participation in international initiatives	Departmental records, interviews with departmental reps and reps of other initiatives	Evaluators based on departmental information
	Opinions of experts regarding participation of Canada	Literature review, interviews with experts	Evaluators based on departmental information
	Level of public and private investment in genomics R&D	Case studies, analysis of secondary data	Evaluators
<b>ULTIMATE OUTCOME</b>			
Enhanced quality of life in terms of health, safety, environment, and social and economic development	Miscellaneous quality of life indicators (e.g., improved health services / treatments, employment opportunities, lifestyle improvement, environmental benefits, etc.)	Case studies, secondary data, special studies, etc.	Evaluators