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Genomics R&D Initiative

ANNUAL PERFORMANCE REPORT 2009-10

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 \$19.9 million/yr **Genomics R&D Initiative (GRDI)** sustains federal genomics research in support of key federal public policy objectives in areas of national interest to strengthen innovation, promote competitiveness, and ensure sustainability for the benefit of all Canadians, under the mandates of the National Research Council of 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) and Fisheries and Oceans Canada (\$0.9M/yr).

Since the implementation of GRDI in 1999, participating departments and agencies have increased their human resource capacity in federal laboratories as well as enhanced the tools, equipment, infrastructure and networks required to undertake genomics R&D and participate in broader, high-impact programs through extensive collaborations with Canadian and international organizations. Investments from the GRDI have allowed public sector scientists to explore promising research avenues towards Canada's economic goals and social wealth and have delivered tangible results that are already helping in many areas important to Canadians. Federal scientists excel in strategically selected areas of genomics research and the GRDI was assessed in its independent formative evaluation as well-managed, effective and efficient. Phase IV of the GRDI ends in March 2011. In a climate of limited resources for government operations, the GRDI forms an integral component of the genomics research program of federal laboratories.

The GRDI has been funded for three-year cycles: Phase I (1999-02), Phase II (2002-05), Phase III (2005-08), and Phase IV (2008-11). Fiscal year 2009-10 was the second year of Phase IV programs. The overall GRDI program framework for Phase IV is presented in the following section, entitled **Phase IV GRDI Impact Areas**. Fiscal year 2009-10 was also a year of forward-looking discussions for future GRDI planning beyond Phase IV.

This Annual Performance Report for 2009-10 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 presents the GRDI program profile and impact areas, its links to departmental objectives and program activity architecture, its relevance to the Federal S&T Strategy, and the research program plans and activities. It then reports on performance for 2009-10 in terms of management, collaborations (**Tables 3 and 4**), capacity building, research and development (summarized in **Annex 3** of Appendix A and illustrated by the summary statistics of outputs in **Annexes 2, 4 and 5** of Appendix A), and outreach.

Acronyms

AAFC	Agriculture and Agri-Food Canada	NRC	National Research Council Canada
ABIP	Agricultural Bioproducts Innovation Program	NRCan	Natural Resources Canada
ADM	Assistant Deputy Minister	OECD	Organization for Economic Cooperation and Development
BC	British Columbia	OGD	Other Government Departments
CanSeq	Canadian Canola Genome Sequencing Initiative	PCR	Polymerase Chain Reaction
CBN	Cellulosic Biofuel Network	PDF	Postdoctoral fellow
CCGI	Canadian Crop Genomics Initiative	PHAC	Public Health Agency of Canada
cDNA	complementary DNA	R&D	Research and Development
CFS	Canadian Forest Service	RMAF	Results-based Management and Accountability Framework
DFO	Fisheries and Oceans Canada	RNA	Ribonucleic Acid
DNA	Deoxyribonucleic Acid	S&T	Science and Technology
EC	Environment Canada	STAGE	Strategic Technology Applications of Genomics in the Environment
FOS	Fully digested fructo-oligosaccharides	STEC	Shiga toxin-producing <i>Escherichia coli</i>
GHI	Genomics and Health Initiative	USDA	United States Department of Agriculture
GRDI	Genomics R&D Initiative		
HC	Health Canada		
HIV	Human immunodeficiency virus		
HQP	Highly qualified personnel		
ISAV	Infectious salmon anemia virus		
LOI	Letter of intent		

Phase IV GRDI Impact Areas

The strategic focus of GRDI research is to contribute solutions to issues of key importance to Canadians – protecting and improving human health, developing new treatments for chronic and infectious diseases, protecting the environment, and managing agricultural and natural resources in a way that is sustainable. Focusing on the specific role of federal government research, it supports evidence-based decision making, policy development, formulation of standards and regulations, and facilitates the development of Canadian commercial enterprises.

IMPROVED PUBLIC HEALTH AND WELLNESS

PLANNED RESULTS

Improve knowledge and understanding of human infectious and chronic diseases for public health-related applications including the development of improved or new diagnostic tools.

Realize crop value improvements in cereals, canola and soybean related to seed development and metabolism (oil content, starch quality, anti-nutritional compounds).

IMPACT AREAS

Phase IV GRDI 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, improved crop yield and nutritional value, and functional foods are the result of genomics-based research towards successful health outcomes.

PLANNED ACTIVITIES

Infectious diseases

- Understand the molecular basis of critical pathogenic and genetic diseases
- Conduct molecular epidemiology of infectious diseases

- Create point-of-care devices for the diagnosis of organisms causing hospital-acquired infections and food and water contamination
- Understand responses to hepatitis C and HIV antiviral treatments
- Clarify the role of vitamin D related to severe influenza infection in seniors
- Develop bacteriophages to prevent common bacterial infections
- Evaluate the role of bacterial pathogens in cystic fibrosis patients

Chronic diseases

- Identify and develop a broad range of targeted therapeutic agents to create the next generation of efficient cancer therapies
- Study interferon-induced hepatic injury
- Identify biomarkers for exposure to mutagenic carcinogens and inhaled contaminants, and effects in cancer, atherosclerosis and asthma development

Food supply

- Decipher the genes that control seed development, carbon partitioning, protein quality, oil quality, starch quality, and the accumulation of anti-nutritional compounds in cereals (wheat, corn), oilseeds (*Brassica*) and legumes (soybean) to improve their productivity and resilience
- Study nutraceutical compounds such as phytosterols, anthramides, and glucans for medical applications

TOWARDS ENVIRONMENTAL SUSTAINABILITY

PLANNED RESULTS

Realize crop value improvements in cereals, canola and soybean related to adaptation to environmental stresses (diseases, pests, drought, cold, and poor soil conditions).

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

Develop and use genomics tools to generate increased understanding of population genetics and structure, as well as of behavioural, physiological and immunological responses to the environment, for the sustainable management of aquatic resources.

Develop genomics applications to understand and remediate environmental contamination and to preserve biodiversity.

IMPACT AREAS

Phase IV GRDI tackles research on issues towards environmental sustainability outcomes such as developing more productive and resistant crops for sustainable agriculture; controlling plant and animal pests and diseases in an environmentally sustainable manner; adapting crops, forests and fish species to respond to climate change related challenges; and protecting endangered species.

PLANNED ACTIVITIES

Agriculture

- Improve the productivity and resilience of Canadian canola crops to meet increasing national and global demands for food and industrial applications (biofuels)
- Develop crops with increased resistance to diseases and insect pests
- Design strategies to engineer increased tolerance to heat, cold and frost in crops

Forestry

- Identify genetic markers for the selection of spruce trees with desired attributes of wood quality and adaptation
- Understand forest host-pathogen genetic interactions to improve sustainable pest control
- Develop and transfer molecular diagnostic tools for the detection and surveillance of forest diseases and pests and phytosanitary certification

Fisheries and aquaculture

- Develop conservation genomics for species of importance to Canada (Atlantic salmon, beluga whales, capelin, Dolly Varden chars)
- Study the migratory fitness of wild salmon
- Identify redfish species and stock structure
- Study salmon diseases (anemia virus, parasites, louse)

Environment

- Conduct molecular characterization of microbial communities in contaminated soil
- Investigate the toxic effects of environmental contaminants on aquatic microbial communities
- Develop conservation genomics of selected wildlife species (birds, mammals)
- Apply genetic markers to resolve species identification and population structure of aquatic invasive species
- Study emerging infectious diseases in native birds and amphibians

EVIDENCE-BASED DECISION MAKING

PLANNED RESULT

Support federal regulatory decisions under the mandates of participating departments and agencies.

IMPACT AREAS

Phase IV GRDI research is developing: diagnostic tools for the detection, surveillance and management of food-borne and water-borne pathogens (salmonella, *Escherichia coli*), human, aquatic, animal and plant pests and diseases, including 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 for the sustainable management of fishery openings and access to global markets. Many of the impact areas already described under the above sections also support evidence-based decision making.

PLANNED ACTIVITIES

- Develop monitoring tools for the management of two important fisheries (beluga and salmon)
- Implement the use of genetic information for mixed-stock fishery management
- Understand population genetics and structure of economically important species to guide management decisions
- Develop diagnostic tools for the management of aquatic animal diseases, important for both the wild fisheries and the aquaculture industry
- Develop and use DNA profile for threatened Northern abalone as evidence to successfully prosecute poachers in court and facilitate out-of-court settlements
- Validate genomics-based procedures to ensure more accurate data for submission under the *Canadian Environmental Protection Act* New Substances Notifications Regulations
- Improve 'early warning' signals to industry regulators with DNA-based techniques used to link environmental exposure of specific substances to potential toxic effects

- Provide species identification for improved decision-making under the *Wild Animal and Plant Protection and Regulation of International and Interprovincial Trade Act*, and the *Convention on International Trade in Endangered Species of Wild Fauna and Flora*
- Evaluate gene expression changes in human cell lines following exposure to wireless telecommunication signals emitted by cellular phones
- Investigate molecular-level effects of environmental contaminants (priority substances and emerging contaminants) on wild species to improve environmental risk assessment/monitoring
- Detect the presence of genetically modified organisms in aquatic ecosystems
- Detect pathogenic micro-organisms in wastewater

FORMULATION OF POLICIES, STANDARDS AND REGULATIONS

PLANNED RESULTS

Support of key federal public policy objectives under the mandates of participating departments and agencies.

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, related to human, animal and environmental health.

Develop genome-science applications to support regulatory 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 sustainable development and responsible use of bio-based products and industrial processes.

IMPACT AREAS

Responsible commercial applications that generate wealth for Canadians are enabled by effective regulatory approaches. Phase IV GRDI generates knowledge to support the formulation of policies, standards and regulations related to the responsible introduction and ongoing monitoring of new products such as pharmaceuticals, medical devices, and food commodities; traceability (animals, plants, food, fish); environmental monitoring and remediation; food additives and labelling. Many of the impact areas already described under the above sections also support the formulation of policies, standards and regulations.

PLANNED ACTIVITIES

- Develop a molecular risk assessment strategy for toxin-producing *E. Coli*
- Understand gene expression patterns linked to dietary fibre and “resistant carbohydrates” to shape a new Health Canada definition for dietary fibre
- Conduct molecular characterization of microbial communities in contaminated soil to validate a new national guidance document under the *Canadian Environmental Protection Act*
- Integrate systems biology approaches in HC regulatory toxicology assessments
- Develop methods for the evaluation of how effluents and chemicals affect aquatic microbial communities, in collaboration with the British Columbia Ministry of the Environment, to be included in risk assessment processes under the Georgia Basin Action Plan and the Chemical Management Plan

SUPPORT FOR CANADIAN COMMERCIAL ENTERPRISES

PLANNED RESULT

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

IMPACT AREAS

Phase IV GRDI scientists collaborate with Canadian companies to support their R&D efforts for the generation of wealth to support Canada's economy.

PLANNED ACTIVITIES

- Conclude a licensing agreement with a Canadian biotech company for the commercial development of antibodies developed by GRDI scientists for cancer treatment
- Collaborate with a commercial partner for the validation of *Salmonella* detection technology developed by GRDI scientists and commercialization to diagnostic laboratories
- *Canadian Canola Genome Sequencing Initiative* Collaborative Research Agreement between GRDI scientists, Genome Alberta and four industry partners (Cargill Limited, Dow AgroSciences Canada Inc., KWS SAAT Ag and RAPOOL-Ring GmbH) formalized in February 2009

Genomics R&D Initiative (GRDI) – Program Profile

Overview

Genomics is the science that studies DNA sequences and their functions in living organisms. The real potential for genomics to provide benefits lies in its power to enable the study of biological systems in their entirety. This provides the understanding of how genes and their products interact in a given environment and insights into how variation in genes impacts biological outcomes such as productivity, quality, and disease resistance.

Genomics has applications in all areas of life. It provides knowledge to support the development of products and processes to enhance the competitiveness of sectors that are key to the economic wealth of Canadian communities (health, agriculture, forestry, fisheries), to advance sustainable environmental technologies, and to improve the quality of life for Canadians now and in the future. Federal, provincial and municipal governments, as well as the private sector, are major consumers of knowledge and tools derived from these technologies.

The Government of Canada, recognizing its legitimate and necessary role in this area, has been a strong supporter of genomics research for over a decade and has funded federal research through the Genomics R&D Initiative (GRDI) since 1999.

The \$19.9 million/yr GRDI sustains federal genomics research in support of key federal public policy objectives in areas of national interest to strengthen innovation, promote competitiveness, and ensure sustainability for the benefit of all Canadians, under the mandates of the National Research Council of 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) and Fisheries and Oceans Canada (\$0.9M/yr). The GRDI has been funded in three-year cycles as shown in Table 1. Phase IV of the GRDI ends in March 2011. In a climate of limited resources for government operations, the GRDI forms and integral component of the genomics research program of federal laboratories.

Table 1: Funding Allocations (\$000)

DEPARTMENT/AGENCY	PHASE I 1999-2002	PHASE II 2002-2005	PHASE III 2005-2008	PHASE IV 2008-2011
Agriculture and Agri-Food Canada	17,000	18,000	18,000	18,000
Environment Canada	3,000	3,000	3,000	3,000
Fisheries and Oceans Canada	2,500	2,700	2,700	2,700
Health Canada / Public Health Agency of Canada	10,000	12,000	12,000	12,000
National Research Council Canada	17,000	18,000	18,000	18,000
Natural Resources Canada	5,000	6,000	6,000	6,000
Medical Research Council ¹	500	-	-	-
Total	55,000	59,700	59,700	59,700

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.

The strategic focus of GRDI research is to contribute solutions to issues of key importance to Canadians – protecting and improving human health, developing new treatments for chronic and infectious diseases, protecting the environment, and managing agricultural and natural resources in a way that is sustainable.

Focusing on the specific role of federal government research, it supports evidence-based decision making, policy development, formulation of standards and regulations, and facilitates the development of Canadian commercial enterprises.

Since the implementation of GRDI in 1999, participating departments and agencies have explored promising research avenues towards Canada's economic goals and social wealth and have delivered tangible results that are already helping in many areas important to Canadians.

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 13).

Governance

An interdepartmental Assistant Deputy Minister (ADM) Coordinating Committee oversees 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 and undertaken. The committee includes members from each of the organizations receiving funding and guest representatives from Industry Canada and from Genome Canada. The Canadian Food Inspection Agency is also represented to plan for future phases of the GRDI.

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 of Canada coordinates interdepartmental activities to manage the GRDI, including the development and implementation of the Results-based Management and Accountability Framework, and chairs both the Coordinating Committee and the Working Group.

Formative Evaluation – A Well Managed, Effective, and Efficient Initiative

A formative evaluation of the Genomics R&D Initiative was conducted in 2006 by an independent 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 for the most part, the six government departments had limited capacity to carry out genomics research before the implementation of GRDI, and that GRDI had been successful in increasing that capacity. Departments supported by GRDI funds have managed to increase their human resource capacity as well as enhance 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 to not only continue support for the Initiative on an ongoing basis, but also to increase its funding base to meet the evolving need for federally performed genomics R&D. Other key recommendations included: 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 has been reported annually in the NRC Departmental Performance Report.

Strong Scientific Performance

A bibliometric assessment of research funded by GRDI between 1996 and 2007 was conducted by Science-Metrix in 2009. Its key findings were that: (1) in terms of their scientific impact, GRDI scientists compared favourably with other federal scientists involved in genomics research as well as with Canadian and international peers, publishing papers

that were more frequently cited than the Canadian (9%) and world (22%) averages in genomics; (2) the federal government has aligned its research intensity in genomics with those of Canada and of the world since the creation of GRDI in 1999; and (3) the average number of genomics papers produced by GRDI scientists increased during the period of support. Further, genomics accounted for an increased proportion of the federal government's scientific output, rising from 6% in 1996 to 9% in 2007.

Planning for the Future – A Renewed GRDI

There have been numerous developments impacting both the scope and direction of genomics research since the GRDI was implemented in 1999. These include emerging issues in terms of threats to health, safety, food, and energy security, largely related to environmental changes, increasing global trade flow, and human demographics; spectacular scientific progress in genomics research generating major economic opportunities; a new science policy in Canada provided by the Federal S&T Strategy; the strong role of Genome Canada to support large-scale genomics research led by universities, and non-federal government and not-for-profit organizations; recognition of genomics as a strength area for Canada; and conclusions from the formative review of the GRDI that recognized its overall success and relevance and provided recommendations for government action.

The GRDI community has engaged in planning activities to realign the GRDI to address these developments, to prepare for next generation technologies that will revolutionize genomics research, and to ensure that the Canadian genomics program continues to provide Canadians and Canadian business with a competitive advantage. A refocused GRDI would be equipped with strengthened delivery mechanisms around strategic priorities and improved inter-departmental integration to best fulfill the role of federal research towards economic and social goals for Canada. It would seek to: 1) deliver high impact solutions to identified enduring and emerging issues through horizontal integration and effective partnerships for economic, social, and environmental benefits for Canadians, and 2) support the priorities, policies and mandates of government through concerted high calibre genomics research in areas where federal laboratories have distinct roles and competencies.

The GRDI is one component of a multi-player context for genomics research in Canada. Given Canada's strength in this area and the multiple academic players, genomics research presents a huge opportunity area for government laboratories to leverage their resources and make an impact through their participation in world-class cutting edge collaborative research. A focused well-coordinated GRDI would be able to better align its investments with those of academia, Canadian provinces, and the private sector.

Results-based Management and Accountability Framework

A Results-based Management and Accountability Framework (RMAF) for the GRDI formalizes the commitment of the departments and agencies involved in the Initiative to report on common performance indicators and guides the structure and content of this 2009-10 Annual Performance Report, which covers year 2 of Phase IV 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** – Increased number 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

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 Canada (NRC). Through its multi-disciplinary approach and research excellence NRC-GHI is supporting goal 2 of the NRC Strategy by 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). GHI also contributes to goal 1 of the NRC Strategy by contributing to the competitiveness of industry by increasing the flow of technologies into high-impact areas of the Canadian economy. Support for these goals 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 all seven priorities of the department's Science and Innovation Strategic Action Plan: *Enhancing human health and wellness through food, nutrition and innovative products; Enhancing the quality of food and safety of the food supply; Enhancing the security and protection of the food supply; Enhancing economic benefits for all stakeholders; Enhancing environmental performance of the Canadian agricultural system; Enhancing the understanding of Canadian bioresources and protecting and conserving their genetic diversity; and Developing new opportunities for agriculture from bioresources.* 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 the 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; and Better Health Outcomes and Reduction of Health Inequalities Between First Nations and Inuit and Other Canadians.* The contribution of GRDI at HC is to generate knowledge that is vital to the effective regulation of health related products. The Departmental Science Plan outlines genomics-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 genomics research 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 GRDI supports the strategic outcome of the Public Health Agency of Canada (PHAC) of *A Healthier Population by Promoting Health and Preventing Disease and Injury.* Two themes guide research activities of the GRDI for PHAC: 1) Public Health Pathogenomics: generating, synthesizing, and moving new knowledge on pathogen genomics and related sciences (proteomics, transcriptomics, metabolomics and bioinformatics) into enhanced infectious disease surveillance, prevention and control programs. New knowledge application takes the form of novel diagnostics, molecular risk assessment tools, vaccines, intervention strategies, and methods for

mitigating antimicrobial resistance. 2) Public Health Genomics: generating, synthesizing, and moving new knowledge in human genomics and related sciences (proteomics, transcriptomics, and bioinformatics) aimed at enhancing diagnostic, health promotion and preventative efforts, such as modulation of risk factors for chronic and infectious diseases and/or predictive genetic screening.

The Canadian Forest Service (CFS) 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 the NRCan Strategic Outcome *Economic Competitiveness and to the Program Activity Innovation from Forests to Market*. It contributes to the Program Sub-Activity: *Innovation Is Robust and Adds Economic Value to Each Link of the Forest Sector's Value Chain – from Forest 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 delivering important practical applications.

Environment Canada (EC) carries out its genomics research through the Strategic Technology 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). Genomics-derived tools are starting to be applied by end users (regulations, enforcement, conservation strategies etc.). However, not all areas of genomics are at the same stage of maturity and extensive validation of some genomics-based approaches and data are needed before being applied to the enforcement and regulatory mandates of the department.

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. The National Aquatic Biotechnology and Genomics R&D Program directly supports one of the three pillars of the Program Activity Architecture at DFO: *Economically Prosperous Maritime Sectors and Fisheries*.

Relevance to the Federal S&T Strategy

The federal science policy framework is provided by the 2007 Federal Science and Technology (S&T) Strategy – *Mobilizing Science and Technology to Canada's Advantage* with its four core principles (promoting world-class excellence; focusing on priorities; encouraging partnerships; enhancing accountability) and its three policy commitments of creating Entrepreneurial, People, and Knowledge Advantages. Canada will achieve a Knowledge Advantage by focusing more of our energies and resources in the priority areas of environmental science and technologies; natural resources and energy; health and related life sciences and technologies; and information and communications technologies.

The S&T Strategy summarizes the role of research pursued inside federal laboratories as upholding regulatory, public policy, and operational mandates in important areas such as health care, food safety, and environmental protection, focusing activities in areas where government is best able to deliver results, and leveraging university and private-sector strengths.

The GRDI is highly relevant to the Federal S&T Strategy, given its strategic focus on supporting government evidence-based decision making, policy and regulatory development, and the development of Canadian commercial enterprises in the key areas of protecting and improving human health, developing new treatments for chronic and infectious diseases,

protecting the environment, and managing agricultural and natural resources in a way that is sustainable.

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.

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 2009-10, 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 + LEVERAGED
National Research Council Canada	6,000	19,797	25,797
Agriculture and Agri-Food Canada	6,000	8,394	14,394
Health Canada	1,635	1,000	2,635
Public Health Agency Canada	2,365	4,500	6,865
Natural Resources Canada	2,000	5,478	7,478
Environmental Canada	1,000	3,200	4,200
Fisheries and Oceans Canada	900	2,097	2,997
Total	19,900	44,466	64,366

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. The overall GRDI program framework for Phase IV is presented in the section entitled **Phase IV GRDI Impact Areas**. Highlights of departmental plans and activities for 2009-10 (second year of Phase IV) are provided in the following sections and additional details may be found in **Annex 1** of Appendix A.

The NRC Genomics and Health Initiative supports five research programs focusing on canola productivity, treatment of brain tumours, near-patient diagnostic devices, cancer identification and treatment, and diagnostic tools for heart attack patients.

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

The GRDI activities at HC continue to strengthen the existing scientific knowledge base under the Departmental Science Plan of HC which outlines the Department's genomics-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 genomics to HC's mandate.

From the perspective of PHAC, genomics of humans and microbes has the potential to radically alter public health practices 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 generates in depth scientific knowledge that is critical for the development of tailored solutions to specific forestry issues, such as evolving needs of Canada's forest industry and threats from insects, diseases and climate change, focusing on species and traits that are of economic importance. The following themes are supported: emerging environmental issues 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, and resistance to biotic and abiotic agents.

Environment Canada has strengthened its internal capacity in the area of the development and application of genomics-based approaches to address

environmental issues related to risk identification, risk assessment and management, conservation biology, wildlife management, and improved enforcement and compliance. Environment Canada 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 genomics, and are acknowledged for their valuable expertise and scientific contributions.

The DFO continues to focus research on three themes: aquatic resource profiling, aquatic animal health, and aquatic ecosystem health. Increased access to genomics expertise and infrastructure through investments in the Maritimes Region has facilitated new internal and external collaborations. Following DFO's competitive funding allocation process for Phase IV of the GRDI funding, researchers from all of the department's regions are now actively engaged in conducting genomics R&D projects to advance the department's strategic research objectives.

Performance

This 2009-10 Annual Performance Report is presented using the performance indicator categories outlined in the GRDI Results-based Management and Accountability Framework, 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.

Management

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

For example at NRC, a formal mid-term review of the Genomics and Health Program was conducted in 2009-10 in accordance with the GHI Governance Framework. The main purpose of the evaluation was to provide NRC with strategic advice on the continued investment in GHI-4 research projects and to make recommendations to the Vice President Life Sciences regarding research project directions. The NRC GHI Expert Panel was asked to consider progress towards milestones and deliverables, project resource management, governance framework implementation, decision-making and risk management, as well as whether or not the overall research direction represented a continued area of relevant investment for NRC and Canada. The Expert panel recommendations were accepted by NRC Executives and have been integrated into project plans for the final year (2010-11) of the GHI-4 Program.

Also at NRC, a call for proposals was launched in 2009-10 for a fifth phase of the GHI program. To ensure that the maximum possible benefit is derived from NRC investments, GHI continues to employ a competitive project selection process that requires the submission of Letters of Intent (LOIs) and sending out full Project Proposals for external review of quality and relevance against pre-determined evaluation criteria. Fifteen LOIs were received, formally reviewed by the GHI Committee of Director Generals to assess their overall feasibility and potential value to support the NRC Strategy. Nine of these LOIs were approved for development into Full Proposals. Three of the existing GHI projects were put forward for renewal (Surgical Simulation, Biorenewable Oil, and Cancer) and six new research areas were approved for consideration in the new phase. This includes research related to Alzheimer's disease, breast imaging, neurochips, vascular implants, anti-infectives, and phage-based bioassays.

At the interdepartmental level, the GRDI working group met on a monthly basis and the GRDI ADM Coordinating Committee met three times to continue the development of a new framework for the GRDI at the end of Phase IV (March 2011). A new model was approved by the GRDI ADM Coordinating Committee in January 2010 to respond to evolving drivers. It describes three components to support shared strategic priorities, individual department/agency priorities and mandates, and common functions for increased effectiveness. It also describes integrated decision-making and governance frameworks. This new model is intended to serve as a catalyst for further discussions integrating input from stakeholders and end-users. Discussions on how to best advance the model for new funding opportunities were deferred to fiscal year 2010-11.

Collaborations

Collaborations are an important part of the GRDI as illustrated by **Tables 3** and **4**. **Table 3** shows GRDI interdepartmental collaborative activities during 2009-10.

Table 3: Interdepartmental GRDI Collaborative Projects

PARTNERS	RESEARCH AREA
AAFC – NRC	Beyond Canola: Genomics for the next generation of Canadian Brassica crops
AAFC – NRC	Transcript profiling of S-methyl-cysteine biosynthesis in developing seeds of common bean
AAFC – NRC	Genetic mechanisms controlling the expression of seed maturation genes in soybean
AAFC – NRC	Harnessing information on disease resistance in pulses using genomics
AAFC – NRC	Associative expression and systems analysis of complex traits in canola
AAFC-HC	Functional genomics of soybean seed proteins-reducing exposure to allergens
EC – NRC	Microbial environmental genomics
EC – DFO	Identification of pathogenic larval parasites in fish and amphibians through barcoding
EC – DFO	Correlation of gene expression profiles with traditional toxicological end-points
EC-HC	Chemical Management Plan
EC-AAFC	Genomics techniques in assessing environmental risks of genetically modified organisms and microbial strains on the Domestic Substances List
EC-HC	Nanotechnology research initiative
EC-HC	Aquatic toxicogenomics of emerging substances

Table 4: Collaborations by Organization Type

TYPE	NRC	AAFC	HC	PHAC	NRCAN	EC	DFO	TOTALS
Universities (Canadian and International)	46	10	14	23	10	26	9	138
Other International Research Organizations	12	2	4	1	5	1	0	25
Other Canadian Research Institutions	3	-	3	1	4	1	0	12
Private Sector	16	-	3	-	1	4	1	25
Other Public Sector Organizations	1	8	3	-	-	2	19	33
Total	78	20	27	25	20	34	29	233

Table 4 shows the extent of collaborations with a wide variety of partners, for a total of close to 240 collaborations leveraging expertise and resources. Many projects involve non-governmental 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 has built strong relationships with German scientists in this area.

The non-for-profit organization Genome Canada and its regional centres are supported by the Government of Canada (\$915M since 2000) to advance large-scale genomics research and enhance Canada's international position. This investment was leveraged to more than \$1.7 billion with co-funding from partners. Synergies developed between federal scientists active in the GRDI and academic scientists active under large-scale programs financed by Genome Canada continue to flourish. Federal scientists are playing a key role in the project *Designing Oilseeds for Tomorrow's Markets*, co-led by the University of Alberta and the NRC, to develop a canola genotype with improved meal quality for the valuable fish and animal feed market. Relationships built through such projects were central to establishing networks funded through AAFC's Agricultural Bioproducts Innovation Program (ABIP). For example the *Cellulosic Biofuel Network* (CBN), led by AAFC, is comprised of more than 40 government and university scientists with the common goal of eliminating barriers faced by the Canadian bioethanol industry.

Brassica researchers at AAFC and NRC collaborated in the design and development of a high density expression analysis platform, a microarray that allows approximately 70% of canola genes to be queried simultaneously. GRDI scientists continued to be key participants of the *Canadian Canola Genome Sequencing Initiative* (CanSeq) Collaborative Research Agreement between NRC, AAFC, Genome Alberta and four industry partners (Cargill Limited, Dow AgroSciences Canada Inc., KWS SAAT Ag and RAPOOL-Ring GmbH) that was formalized in February 2009. This large-scale collaboration ensures strong participation of Canada in a multi-national project aiming at sequencing two chromosomes of the *B. rapa* genome, develop a draft *B. napus* genome sequence and identify genome wide nucleotide variation in *B. napus*.

The NRCan 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 white spruce, a species of key economic importance. 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.

Scientists from NRC participate with the University of Ottawa in a joint Genome Canada Technology Development project. Researchers at the University of Ottawa demonstrated a prototype device, the proteomic reactor, designed to overcome the problem of protein sample loss during preparation. This device enables scientists to process minute levels of protein and opens the possibility of studying proteins in individual rare cells, such as stem cells, that appear in only trace levels in the body. Competencies developed at the NRC's Genomics and Health Initiative (NRC-GHI) over the past six years are critical for the advancement of this technology. As part of NRC-GHI's investments in Pathogen Detection and Biochip technologies, approaches for capturing and interrogating very small numbers of pathogens have been in development since 2005. The merging of these two teams creates a critical mass of expertise that is now being successfully applied to further develop and expand the proteomic reactor technology to chip proteomic reactors. NRC-GHI microfluidic expertise will be leveraged to make the reactor more efficient with automated fluidic stations. In addition, NRC-GHI cell capture expertise will be leveraged to develop automated proteomic reactor kits and to demonstrate their novel single cell analysis applications in the field. It is expected that the single-cell processing on the reactor coupled to fluorescence detection will provide a sensitivity allowing the measurement of proteome profile changes in single cells.

Scientists from PHAC collaborate with researchers and provincial public health and agriculture colleagues across Canada to study the virulence of *Salmonella* exposed to antimicrobials.

Genomics R&D Capacity

As confirmed by the Formative Evaluation completed in 2006, most of the participating departments had limited capacity to carry out genomics research before the implementation of GRDI. Departments supported by GRDI funds are now able to undertake genomics R&D and contribute to broader, high-impact programs established through formal and informal collaborations with Canadian and international organizations.

In 2009-10, the GRDI supported 479 scientific and technical staff, 45 post-doctoral fellows, 74 students (PhD, MSc, BSc, and Co-op), 1 visiting scientist, and 3 administrative officers, for a total of 602 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. Additionally, a new Confocal Laser Scanning Microscope was purchased at NRC and is being used for high resolution imaging of tumour cells.

To achieve the throughput desired in the GHI cancer project, a dedicated lab was set up at the NRC Institute for Biological Sciences for higher throughput antibody production using the King Fisher Flex 96 system. The NRC Institute funded renovations and the GRDI provided \$129,000 to equip the facility.

Research and Development

Research and Development is the central component of this Initiative, together with activities surrounding the conduct of R&D that 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 2009-10 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 in areas related to adaptation to biotic and abiotic stresses (e.g. resistance to disease, tolerance to cold), as well as seed development and metabolism (e.g. industrial applications, health and nutrition benefits and enhanced end-use quality);

- 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; further understanding of behavioural, physiological and immunological responses to the environment; and through the management of aquatic animal diseases;
- 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, related to human, animal and environmental health;
- Improve knowledge and understanding of human infectious and chronic diseases for public health-related applications including the development of improved or new diagnostic tools;
- Increase knowledge to support forest generation and protection, and to address 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.

The **Phase IV GRDI Impact Areas** section provides the strategic directions and high-impact research areas selected for 2008-11. A detailed account of the results achieved in 2009-10 against planned results as listed in the 2009-10 Report on Plans and Priorities is provided in **Annex 3**.

An important goal of the GRDI is to ensure that federal research scientists remain credible 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 for 2009-10, while **Annex 4** of Appendix A provides additional detail broken down by department/agency:

- 196 publications in refereed journals;
- 98 publications in conference proceedings;
- 136 invited presentations;
- 26 technical reports;
- 21 other publications including books and book chapters;
- 177 presentations and posters at national and international conferences;
- 6 disclosures filed;
- 2 licenses issued;
- 7 patent applications;
- 16 patents issued;
- 6 material transfer agreements;
- 89 collaborative agreements;
- 1 genomics-related database developed and launched;
- 4 bioinformatics programs developed; and
- numerous GenBank deposits (various insect pathogens, hemlock looper).

Outreach

Direct and indirect public communications are an important aspect of the GRDI. External web pages and project wikis were developed; interviews to the media were given; community presentations and tours were organized; presentations were given to students in public schools; brochures and factsheets were written; and GRDI scientists participated in science fairs and student mentorships. Additional information detailing department/agency activities is provided in **Annex 5** of Appendix A.

Appendix A

Supplemental Performance Details

Annex 1 – GRDI Funded Projects by Department

National Research Council Canada

Biochips for the Understanding and Diagnosis of Human Disease

This project aims to develop new tools for understanding the molecular processes underlying critical pathogenic and genetic diseases. The goal is to create small and efficient point-of-care diagnostic devices integrated onto a single silicone chip (biochip) with the capacity to rapidly detect specific pathogenic markers. In particular, this device will focus on diagnosing infectious agents responsible for hospital-acquired infections and threats to food and water safety.

Biorenewable Oil for Food and Fuel

The goal of this project is to apply genomics-based approaches to improve the productivity, yield, oil content and resilience of Canadian canola crops in order to meet increasing national and global demands for this vital crop for both food (oil for cooking) and industrial / non-food applications (biofuels).

Identification of Proteins Targeting the Tumour Microenvironment for Therapeutic Applications

The objective of this project is to tackle the complex treatment of cancer by identifying and developing a broad range of targeted therapeutics agents that can be used to create the next generation of promising and more efficient cancer therapies.

Under its GHI program, NRC also invests in health-related projects that do not have an explicit genomics component. These projects include:

Heart Disease: Better Tools for Better Treatment

The objective of this project is to bring closer to clinical practice, a number of innovations for better diagnostic and imaging tools that can be employed in the management of heart disease.

Patient-Specific Virtual Reality Simulation Systems for Surgical Oncology

The objective of this project is to develop a virtual-reality based rehearsal (training and planning) system, integrated with Magnetic Resonance Imagery, for patient-specific surgical oncology.

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, oat, triticale), oilseeds (Brassica/Arabidopsis) and legumes (soybeans, pulses)

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

- Development and validation of toxicogenomic tools, and integrated systems biology approaches in regulatory toxicology
- Environmental health applications of toxicogenomics and proteomics. Identification of exposure and effect biomarkers for mutagenic carcinogens in complex environmental matrices
- Molecular genomics applied to radiation risk assessment
- Colon epithelial cell genetic response to dietary fibre

Public Health Agency of Canada

- Host genomics of hepatitis C antiviral treatment response
- A molecular risk assessment strategy for non-O157 Shiga toxin-producing *Escherichia coli*
- Development of high-throughput comparative genomic methods for studying the molecular epidemiology of infectious diseases
- Identification and characterization of virus – host cell protein-protein interactions
- Influence of genetic variability in innate immunity pathways and micronutrient status on infectious disease outcomes with specific focus on severe influenza infection
- Bacteriophages and prevention of common bacterial infections
- MicroRNAs and infectious disease: a novel regulatory mechanism in host-pathogen interaction
- The application of multiplexed, parallel, high throughput, real-time PCR based pathogen detection system for HIV drug resistance testing
- Genetic variability and virulence studies in emerging antimicrobial resistant organisms
- Genomic analysis of “novel” chronic bacterial pathogens in cystic fibrosis patients
- Pyrosequencing and assembly of viral quasispecies

Natural Resources Canada

Genomics/proteomics for identifying commercially desirable tree genes

This area of work aims at developing methods, tools and databases for the discovery of trees possessing commercially desirable attributes and for the conservation of genetic resources. Candidate genes for wood quality, growth and disease resistance are characterized and transferred to tree breeders and the scientific community. Research projects include:

- Discovery of genes controlling wood and fibre traits in white and black spruces and development of genetic markers for the selection of trees with desired attributes
- Functional genomics in spruce
- Genome scan to reveal gene islands underlying productivity and adaptation in spruce

- Isolation and identification of defense genes, and molecular markers associated with disease resistance of *Pinus monticola* to blister rust fungus
- Understanding tree defense response through genomics

Understanding host-pathogen genetic interactions to improve sustainability and productivity

This area of work aims at strengthening basic knowledge of forest pests and their pathogens. Genomics is used to understand pathogen modes of action, host specificity, host-pathogen interactions, ecology, and impact on host populations. The knowledge advances the search for new active ingredients and target sites for the next generation of biopesticides and new and improved biocontrol agents. Innovative molecular technologies for pest diagnostics and identification is also pursued and transferred to end-users in Canada and internationally for surveillance of diseases and pests, and phytosanitary certification. Research projects include:

- Proteomics regulation of virus/larva interactions
- Molecular screening for pathogens of indigenous and introduced coleopteran forest pests
- Comparative genomics of forest defoliators: from DNA to mitigation
- Genomics of fungal tree pathogens
- Emerald ash borer sensory genomics: mining for odorant receptors mediating host-finding and mate-finding
- Douglas-fir resistance to root disease and other stress agents

Environment Canada

- Design and optimization of novel DNA microarrays for environmental effects monitoring
- Application of genomics for microbial source tracking and assessing microbial water quality
- Aquatic toxicogenomic of emerging products: nano/biotechnology
- Validation of genomics tools for the prediction of environmental effects: response of fish to contaminated sediments
- Genomics application in environmental risk assessments of genetically modified organisms and other biotech products

- Development and standardization of test methods using environmental genomics techniques
- Gene expression technologies – applications to wildlife toxicology
- Development and validation of a lobster toxicogenomic array - correlation of gene expression profiles with traditional toxicological end-points for contaminant exposure
- Aquatic toxicogenomic tools for risk assessments and environmental effects of chemicals and complex mixtures
- Development and application of novel genomics-based micro-array techniques for the detection of environmental microorganisms in wastewater
- Breeding behaviour and population history of the red-listed Yellow-breasted Chat in British Columbia: a pilot study
- Establishing molecular assessment techniques for emerging infectious diseases in native amphibians; laboratory and sampling technique comparisons
- Comparative genetic diversity of captive and wild of Loggerhead Shrikes
- Conservation genetics of Leach's Storm-petrels
- Conservation genetics of Northern Gannets
- Conservation genetics of Haida Gwaii Thrushes
- Hybridization between eastern wolves (*Canis lycaon*) and other canids: an example of contemporary evolution in human-modified landscapes
- Genetic characterization of strains of *Pasteurella multocida* isolated from large-scale avian cholera outbreaks across Canada
- Ontario Canada goose population harvest discrimination
- Characterization and sequencing of avian influenza viruses from birds in eastern Newfoundland
- Inter-island movements of introduced black-tailed deer in Haida Gwaii

Fisheries and Oceans Canada

Genome-based monitoring to help in the management of two important fisheries:

- Using genetics to improve conservation of beluga whales (*Delphinapterus leucas*) in the western Canadian Arctic.
- Genomics of migratory fitness in wild salmon

Increased understanding of population genetic and structure of important economic fisheries:

- Conservation genomics of Atlantic salmon in Newfoundland and Labrador: assessment of genetic differences between wild and aquaculture strains and analyses of genetic structuring for the identification of important within-species biodiversity
- Discriminating capelin populations in the northwest Atlantic
- Redfish (*Sebastes sp.*) species identification and stock structure based on genetic analysis of archived otoliths
- Dolly Varden char population structure and genetic diversity in the western Arctic
- Investments in the Aquatic Biotechnology Service Lab at the Bedford Institute of Oceanography

Increase understanding of the behavioural, physiological and immunological responses to the environment:

- Microbial characterization of produced water and its influence on the microbial community in the marine environment around the Hibernia production platform
- Application of genetic markers to resolve species identification and population structure of aquatic invasive species

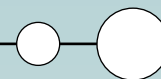
Management of aquatic animal diseases, important for both the wild fisheries and the aquaculture industry:

- Immune function of salmon and disease resistance against infectious salmon anemia virus (ISAV) – phase 2
- The effects of wild and captive rearing environments, and associated parasite and pathogen regimes, on the diversity and nature of genetic variation in Atlantic salmon
- Host parasite interactions: a functional genomics approach to characterising salmonid responses to the salmon louse

Appendix A

Supplemental Performance Details

Annex 2 – Highly Qualified Personnel (HQP) by Department



National Research Council Canada

184 research and technical personnel were supported under the initiative:

- 35 research officers
- 72 technical officers
- 56 research associates
- 18 students
- 3 administrative

Agriculture and Agri-Food Canada

157 research and technical personnel were supported under the initiative:

- 64 research scientists
- 3 Postdoctoral fellows
- 86 technical positions
- 4 university students (graduates)

Health Canada

42 research and technical personnel were supported under the initiative:

- 13 principal Investigators
- 13 research professionals
- 1 technical position
- 6 Postdoctoral fellows
- 9 university students
(2 PhD, 3 MSc and 4 undergraduates)

Public Health Agency of Canada

45 research and technical personnel were supported under the initiative:

- 17 principal investigators
- 3 research professionals
- 8 technical positions
- 8 Postdoctoral fellows
- 9 university students

Natural Resources Canada

96 research and technical personnel were supported under the initiative:

- 12 research scientists
- 38 biologists/technicians
- 22 Postdoctoral fellows
- 1 visiting scientist
- 23 university students
(14 MSc and PhD, 9 undergraduates)

Environment Canada

31 research and technical personnel were supported under the initiative:

- 20 research scientists
- 1 research professionals
- 1 research technicians
- 1 chemist
- 1 Postdoctoral fellows
- 7 students (2 PhD, 2 MSc, 3 undergraduates)

Fisheries and Oceans Canada

47 research and technical personnel were supported under the initiative:

- 18 research scientists
- 20 technical staff
- 5 Postdoctoral fellows
- 4 students

Appendix A

Supplemental Performance Details

Annex 3 – Planned Results versus Achieved Results (2009-10)

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

Scientists at NRC made good progress towards applying the advanced materials and fabrication techniques used in microphotonics to an evanescent field sensor targeting the detection of human pathogens. They published the first reported example of a waveguide-based biosensor array where they demonstrated successful mammalian antigen-antibody binding using a four and six sensor array. The team is on track to deliver a prototype device by the end of fiscal year 2010-2011.

Building a sustainable pipeline of protein-based tumour-targeting agents that will act as prospective therapeutics is the goal of the NRC Cancer project. In April 2009, Alethia Biotherapeutics exercised its option to license the rights on NRC's anti-clusterin antibody technology. The company is working with NRC to develop anti-clusterin antibodies for the treatment of cancer. In September 2009, the license was amended to include a novel clusterin-binding peptide as a tumour imaging agent.

Planned Result 2

Realize crop value improvements in cereals, soybean and canola through improvements in areas related to adaptation to biotic and abiotic stresses (e.g. resistance to disease, tolerance to cold), as well as seed development and metabolism (e.g. industrial applications, health and nutrition benefits and enhanced end-use quality).

Achieved Result 2

The genome of the fungus responsible for blackleg disease of canola has been sequenced. This has allowed the identification of specific genes which encode proteins that interact with the plant to cause disease. Knowledge of the mechanism of action of these genes will allow the development of resistant varieties.

Genes activated by cold stress have been identified in a range of cold tolerant plants related to canola. These genes could provide a novel source of cold tolerance which could be transferred to canola.

Elimination of storage proteins in a model plant related to canola was found to result in a general increase in expression of other proteins expressed in developing seeds. This raises the potential to increase the expression of high value proteins in seeds of crop plants.

Genes regulating biochemical pathways involved in isoflavonoid production were characterized in soybean. Isoflavonoids are known to provide human health benefits.

Several genes associated with virulence have been isolated from the fungus causing wheat leaf rust and novel techniques to study their role in causing the disease have been developed. Knowledge of the mechanisms will allow durable rust resistance to be deployed.

A gene that is a negative regulator of plant defense against the pathogen causing rust diseases in wheat was found to also act as a positive regulator against the pathogen causing fusarium head blight. This provides us with the ability to identify resistance mechanisms against both disease types.

The NRC biorenewable oil team has been characterizing 29 genes that play an important role in canola crop improvement. Results from five prototypes tested in the field in collaboration with AAFC were analyzed in 2009-10. Compared to the controls, two prototypes confirmed improved oil content and one prototype confirmed early flowering and increased seed size:

- Early flowering (10 days earlier) – earlier flowering would mean missing the extremely hot temperatures in July that can negatively impact oil content and yield;
- Increased seed size (10%) – increased seed size results in enhanced vigour, enabling the seed to cope with early stresses;
- Increased oil content (2-8%) – with each % increase in oil content creating an additional \$75M activity in the Canadian economy.

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; further understanding of behavioural, physiological and immunological responses to the environment; and through the management of aquatic animal diseases.

Achieved Result 3

2009-10 saw the continuation of twelve projects initiated at DFO in fiscal year 2008-09 following a competition to select the projects that respond most to the department's priorities and strategic outcomes, as described below.

Through the GRDI, DFO has initiated activities that seek to use genome based monitoring to help in the management of two important fisheries.

Genome based monitoring of beluga whales (*Delphinapterus leucas*) in and connected to proposed marine protected areas within the Beaufort Sea

The beluga whales of the Beaufort Sea constitute an important subsistence fishery for the local Inuit populations, with an average Canadian landed catch of 111 per year (1990-1999). This study was undertaken to determine the population structure of these Beluga such that the sustainability of the population can be maximized through a harvesting plan based on sound scientific data, ensuring that this important fishery is open and productive into the future. Data collection on this project is continuing, with analysis and interpretation of the results expected to begin in late 2010.

Genomics of migratory fitness in wild Salmon

This study has uncovered a highly prevalent signature associated with premature mortality of adult salmon returning to the river to spawn. This same signature is present in smolts before they leave the river; reduced prevalence of this signature in the first three months of ocean residence is potentially indicative of high mortality that could account for the loss of >27 million smolts in 2006. Scientists hypothesize that this signature is associated with viral activity.

DFO has initiated several projects to generate increased understanding of population genetics and structure of important economic fisheries. These include:

Genetic identification of Atlantic salmon from Newfoundland and Labrador in relation to nearby aquaculture and escapes into the wild

Samples were collected from about 30 rivers across Newfoundland and Labrador, DNA samples were extracted and duplicate samples were archived. Five new loci were optimized for PCR and used with 10 existing loci to genotype 564 samples collected in 2008. Currently, the 2009-2010 samples are being genotyped using the same 15 loci.

Discriminating capelin populations in the northwest Atlantic

Capelin is an important food source for many species in the north Atlantic and Arctic Oceans and is also commercially exploited. It is a short-lived species which for the most part spawn on beaches. In Europe genetic results have indicated a single large population, however recent analyses of a detailed sampling program in the northwest Atlantic has revealed genetic substructures that may be important in predicting climate change movements and for managing the stocks.

Redfish species (*Sebastes sp.*) identification and stock structure based on genetic analysis of archived otoliths

In this project, genetic analyses were carried out using the material adhering to the otoliths collected since 1974 to determine if the species composition of a given year-class was a key factor in the recruitment failure or success. The results indicate that one particularly strong year class (1980) supported the fishery for more than 20 years.

Genetic variability in wild populations of chars in the Arctic

This project has been extended to include samples from Alaskan rivers in collaboration with US Fish and Wildlife Service and laboratory studies continue. Additional samples representing southern chars (i.e., British Columbia) are being sought through other collaborations. Preliminary results have confirmed that Northern Dolly Varden constitute a distinct taxon from other Dolly Varden sub-species. This very important finding supports the 'designatable unit' structure presently being used by the Committee on the Status of Endangered Wildlife in Canada in its review of this taxon.

Alongside the projects undertaken, DFO has made investments into its Aquatic Biotechnology Service Lab at the Bedford Institute of Oceanography

The Aquatic Biotechnology Lab participated in 8 additional projects, bringing in an extra \$78.6K O&M funding. Under this project the optimal extraction procedure for samples collected on filter paper was determined and PCR conditions for various loci required for species identification were optimized.

Several new projects serve to increase our understanding of the behavioural, physiological and immunological responses to the environment. These projects include:

Microbial characterization of produced water and its influence on the microbial community in the marine environment around the Hibernia production platform

This project has developed a new meta-genomics technique for microbial community structure and function to delineate the impact zone around offshore oil and gas facilities. To date, results have shown a near-field impacts (<500m) around the Hibernia platform. Further, a data base was developed that will be used to monitor time-series changes in microbial population responses to alterations in habitat quality related to both natural and anthropogenic processes in the Gully Marine Protected Area.

Application of genetic markers to resolve species identification and population structure of aquatic invasive species

Traditionally, genetic markers are hard to find in non-model organisms because very little information about their DNA is already known. A revolutionary new technology, 454 pyrosequencing, was used to identify

and isolate 12 new microsatellite markers in *Didemnum vexillum*, a high risk colonial tunicate species with a global invasion history. These markers are unmatched for information content at the level of populations within species because their high mutation rate allows very recent population level processes to be elucidated, which is critical for examining invasion dynamics. Scientists at DFO are possibly the first to implement population level screening on any organism using the polymorphic markers identified using this novel technique.

The management of aquatic animal diseases is important for both the wild fisheries as well as the aquaculture industry. Research under the GRDI at DFO continues to focus on issues such as:

Immune function of salmon and disease resistance against infectious salmon anemia virus

Salmon were injected with an infectious salmon anemia virus (ISAV) non-virulent strain and, as expected, only low levels of fish mortality were observed. Surviving individuals later re-challenged with a virulent ISAV strain saw a higher survival rate. Interestingly, the non-virulent ISAV strain was still detected in the immunized fish at low levels. It seems likely that infected fish may never be completely clear the virus post infection, and are long term potential carriers of the disease.

The effects of wild and captive rearing environments, and associated parasite and pathogen regimes, on the diversity and nature of genetic variation in Atlantic salmon

Recent increases in marine mortality of Atlantic Salmon have resulted in severe population declines. The number of adult returns is now estimated to be in the low hundreds, and recent surveys have failed to detect juveniles in over 90% of the formerly inhabited rivers of the inner Bay. In response to the precipitous decline of adults, and high rate of marine mortality, DFO collected several hundred juveniles from the two largest rivers of the inner Bay of Fundy, the Stewiacke and Big Salmon. These individuals were reared in captivity, genotyped, placed in population-specific pedigrees, and spawned using modern genetic principles intended to minimize loss of genetic variation due to random genetic drift. The resulting offspring were both reared in captivity under standard hatchery conditions, and released into native River habitat for exposure to wild conditions and natural selection. Juveniles from both environments were then

collected, tissue sampled, genotyped, and placed into population-specific pedigrees for production of the next generation of endangered Atlantic Salmon. Preliminary results suggest that maintenance of populations in semi-wild conditions may be important in minimizing loss of genetic variation. Indeed, exposure of early life-stage juveniles to wild conditions, as is done in the inner Bay of Fundy Atlantic Salmon recovery program, may also help minimize selection-driven changes in allele frequency.

Host parasite interactions: a functional genomics approach to characterising salmonid responses to the salmon louse

This project has revealed important differences in the transcriptomic responses of resistant (pink) and susceptible (chum, Atlantic) salmon following exposure to salmon lice. Using a newly developed microarray, the transcriptomic responses of salmon lice to gradients of temperature, salinity or emamectin benzoate (a pesticide) have been profiled. These data have applications in the development of novel management strategies for salmon lice including salmon breeding programs, vaccines and the early detection of resistance to chemotherapeutants.

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, related to human, animal and environmental health. Improve knowledge and understanding of human infectious and chronic diseases for public health-related applications including the development of improved or new diagnostic tools.

Achieved Result 4

Work under the health portfolio is undertaken to generate, synthesize, and translate new knowledge in pathogen and human genomics to: strengthen infectious disease surveillance, prevention and control through applications such as diagnostics, molecular risk assessment, vaccines, intervention strategies, mitigation of antimicrobial resistance; and, develop applications to diagnose and prevent diseases and promote health through predictive genetic screening and/or modulation of gene-environment interactions.

Molecular genomics applied to radiation risk assessment

Biological effects of radiation emitted by natural sources (radon, UV rays) and devices such as cell phones were investigated. Using controlled radiation sources and rodents and human cell lines as experimental models, potential stress responsive genes were identified. These biomarkers are being validated by further experiments that will seek understanding of the biological mechanisms of gene-environment interactions in conditions of long term exposure. Health Canada would use this data to develop more refined standards of maximum exposure to radiations and better regulate radiation emitting devices and exposure in living /working environments.

Environmental health applications of toxico-genomics and proteomics

Numerous environmental and occupational exposure scenarios present complex mixtures of chemical carcinogens (e.g., polycyclic aromatic compounds). Health Canada researchers have examined biological pathways in cultured transgenic murine cells that are altered by chemical mixtures presented as standard reference materials (e.g., diesel particulate matter and coal tar extract). Novel approaches have allowed earmarking thirteen biomarker candidates for further investigation, using whole genome DNA microarray for genomic analyses, tandem mass spectrometry for proteomic analyses, and bioinformatics analyses to integrate the results. Upon validation, biomarkers will be discovered for pathologic changes linked to exposure to complex mixtures of carcinogens and other toxicants encountered in environmental and occupational settings. The understanding of physiological changes linked to adverse health effects will assist regulatory decision-making.

Development and validation of toxicogenomic tools, and integrated systems biology approaches in regulatory toxicology

The evaluation and regulation of environmental contamination require high-throughput assays, in parallel with integrated systems-level approaches. These methods need to be internationally validated and serve as platform methodologies applicable to a number of different model systems. These approaches have demonstrated that some of the traditional biological pathways of carcinogenesis induced by environmental contaminants are not the only mechanisms leading to toxicity. Using model

carcinogens like benzopyrene and cigarette smoke, new approaches for identification of biomarkers and health effects were developed by Health Canada. These methods integrate mRNA, microRNA and protein analyses. With this work, Health Canada contributed significantly to the international standard setting exercise led by OECD, and provided new data for toxicants on the Chemical Management Plan priority list.

Investigations on colon epithelial cell genetic responses to dietary fibre

The bacterial flora in the large intestine carries out many bacteria-specific metabolic reactions, including the fermentation of dietary fibre and other materials that enter the colon. Conflicting results regarding any potential benefits of fermentation have plagued the scientific literature for years: one problem is the utilization of different sources of fermentable materials for different studies. These concerns are of particular interest to agencies developing a definition of dietary fibre that could encompass materials from various sources, including man-made carbohydrates. In order to address these questions, Health Canada undertook a systematic study of the source of fermentable carbohydrate on diet-gene interactions in colonic epithelia cells in healthy rats as a model system. The results showed that colon epithelia do respond to fermentation of both wheat bran partially digested by bacteria and fully digested fructo-oligosaccharides (FOS) but that wheat bran fibre (up to very high levels) and lower levels of FOS led to relatively few large-scale changes in individual gene mRNA levels. Higher levels of FOS elicited many different changes, including genes associated with mineral absorption and cell death. This effect was not due solely to the extent of fermentation, since wheat bran fibre (fed at similar total amounts of fermentable material) showed a much different response. Some of these changes are opposite to those expected from physiological outcomes, making interpretation of the gene expression results difficult and highlighting the danger of extrapolating gene response changes to predict physiological outcomes. However, results showed that the source of fermentable material can significantly affect gene responses suggesting that not all fermentable materials should be treated equally. Health Canada continues to study other biomarkers to help elucidate the gene response mechanisms and to investigate any potential effect on colon and/or host health, eventually leading to refine food labelling policies addressing health claims of foods.

Research at PHAC continued to focus on the development and application of “omics” tools to reduce exposure to food borne pathogens in the form of a novel, generalized approach for genetic fingerprinting of bacterial pathogens using comparative genomics. The approach is being used to develop a series of assays that are adaptable to different existing and emerging platforms, providing a range of solutions that can be tailored to available resources of laboratories. A computer program to analyze genome sequence data and facilitate the design of assays was developed and a series of assays for several priority pathogens (*Listeria monocytogenes*, *Campylobacter jejuni*, *verotoxigenic Escherichia coli*) are in various stages of development while the method is field-tested by collaborators in Canada and the United States through deployment in molecular epidemiological analysis of various datasets. Additional work on emerging platforms has also been undertaken: a series of prototype assays have been designed and fabricated, and protocols were developed and validated. Retrospective analysis has allowed the identification of a set of 20 genes that provide 90% of the genotyping resolution at half of the cost and effort of the current assay. This set of genes is currently being targeted for a rapid screening assay using the Luminex liquid array platform. The arrays will be ultimately used for population-screening to uncover markers with increased association with human clinical isolates. Software tools for analysis of raw data and statistical analysis of population screening level data have been developed.

Shiga toxin-producing *Escherichia coli* (STEC) can cause massive outbreaks and the potentially fatal hemolytic uremic syndrome. Although O157:H7 is the most common STEC serotype, more than 200 virulent non-O157 isolates have emerged globally that are associated with human disease. While some non-O157 STEC strains may also be fatal, others are associated with only mild diarrhoea or with no human disease at all. The lack of full genome sequence data for non-O157 STEC has hampered scientific discovery into the genetic basis for these virulence differences. Research at PHAC seeks to identify the critical STEC genetic elements and virulence factors associated with severe and epidemic disease. This will enable the development of a molecular risk assessment strategy using specific nucleic acid-based diagnostic tests to rapidly identify and respond to emerging non-O157 STEC that pose a serious public health risk to humans.

In 2009-10, GRDI research continued to develop new diagnostic technologies applicable to both large scale surveillance screening and clinical monitoring. For example, the development of a high throughput, rapid, inexpensive real-time PCR based chip array for HIV drug resistance testing has been initiated. The 52 primer and probe sets required to detect the designated HIV drug resistance mutation have now been designed. All control plasmids containing the relevant HIV drug resistance mutations have been designed and synthesized. Current work involves the optimization and validation of the primers/probes against control reagents.

Other scientists are studying the main divergent responses (clinical phenotypes) to antiviral treatment of Hepatitis C Virus infection: “Responders” and “Non-responders”, as a significant proportion of infected patients fail to respond to the best antiviral therapy currently available. Numerous studies have demonstrated that therapeutic outcomes are influenced by patient genetics. Scientists are applying state-of-the-art technologies, namely high density DNA microarrays, DNA sequencing, and bioinformatics to identify candidate host genetic polymorphisms (biomarkers) associated with treatment response.

The majority of cystic fibrosis patients are colonized with *Pseudomonas aeruginosa*; however their respiratory infections are poly-microbial in nature. The role of host oropharyngeal flora bacteria has been investigated and clinical studies have recently revealed that *Streptococcus milleri* levels are contributing to acute respiratory exacerbations in some cystic fibrosis patients. Currently there are no reliable diagnostic assays or tools to assess the level of pathogenic *S. milleri* isolates in chronic lung infections. Scientists at PHAC continue to assess bacterial genomes of each *S. milleri* species to facilitate the development of targets for diagnostic and therapeutic assays for cystic fibrosis.

Researchers at PHAC continue to investigate genetic polymorphisms associated with severe influenza in the vitamin D biosynthetic/immunomodulatory pathway. While recruitment continues, current analyses remain underpowered. Further recruitment of subjects is being pursued in order to enhance the power of detecting an association between single nucleotide polymorphism markers and severe influenza. Identifying the molecular processes underlying severe influenza infection can facilitate the develop-

ment of rational intervention strategies, particularly via micronutrient supplementation.

Researchers at PHAC investigated newly discovered regulatory molecules produced following viral and prion infection, that contribute to the regulation of innate immune responses. These molecules are potential prime targets for therapeutic interventions in immune related diseases or infections in which excessive or chronic inflammation is damaging. In addition they may ‘fine-tune’ responses induced by vaccination. Cell lines expressing a number of viral immunomodulatory proteins have been constructed. MicroRNAs expressed in the brains of prion infected mice have also been identified. Potential targets of one of these microRNAs have been identified using a combination of functional genomics analyses. Future experimental work aims to further uncover the mechanisms by which microRNAs regulate the innate immune response to infection.

Scientists at PHAC continue to explore high mutation rates in RNA viruses, including Human Immunodeficiency Virus, Hepatitis B Virus, and Hepatitis C Virus that result in the generation of variant genomes, called *viral quasispecies*. Characterization of these viral quasispecies genome populations from infected individuals, such as diversity, recombination and evolution, is important to understand these viruses and to develop control strategies, diagnostics, vaccines, and antiviral therapies.

Viruses have an absolute reliance on host cells for their replication cycle and therefore must physically and functionally interact with their host proteome. These protein-protein interactions not only create cellular environments conducive to virus replication, but also affect normal cellular functions the consequences of which often result in life threatening pathologies. A team of PHAC scientists continues in its efforts to identify human proteins that virus proteins interact with in order to provide insight into the mechanisms of virus replication and pathogenesis and to uncover novel host therapeutic targets. Namely, a series of vectors were developed that contain retrovirus backbones and allow straightforward generation of stable cell lines. Genes were then cloned into these vectors and confirmed expression of Hepatitis C related proteins. Other recent progress includes the development of cell lines that stably express viral proteins of interest for Hepatitis C and the human papilloma virus.

Work is underway on the Ebola virus. Cellular localization for many of these proteins is being evaluated by indirect immunofluorescence, and mass spectrometry identification of interacting proteins has been performed for the hepatitis C virus proteins. Finally, a database containing all the relevant viral proteins should be completed shortly, allowing functional studies to begin.

Bacteriophages kill specific bacterial cells and therefore represent ideal alternatives to disinfectants and antimicrobial agents for the prevention and therapy of infections. However, before being used in humans and animals, bacteriophages must be characterized in detail with regards to their spectrum of activity as well as to their genetic structure, to ensure efficacy and safety. Researchers at PHAC are assembling a collection of bacteriophages for characterization of activity against an *E. coli* collection. Cocktails of phages with optimal characteristics for therapy and prevention of specific infections will be defined. The bacteriophages forming these cocktails will be characterized in detail for their morphology and genome sequences. Currently, progress has been made on the development of a new method to identify and optimize isolation of bacteriophages from environmental samples. This has resulted in the identification and characterization of bacteriophages with a potential for therapeutic use against target Methicillin-Resistant *Staphylococcus aureus*, bacteria, as well as the full genome sequencing of numerous relevant bacteriophages, elucidating genes of interest.

Planned Result 5

Increase knowledge for 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

Increased knowledge of genomics-based pest control and diagnostics

The genomics program of NRCan provides knowledge of forest pests and their pathogens, including pathogen modes of action, host defence mechanisms, and host-pathogen interactions. 2009-2010 saw the ongoing testing of insect killing pathogens (entomopathogens), which include various virus families, microsporidia and fungi, of three

economically important invasive coleopteran species: emerald ash borer, mountain pine beetle, and brown spruce longhorn beetle. Expressed sequence tags generated from emerald ash borer revealed the presence of compounds homologous to known chemosensory proteins, odorant-binding proteins and gustatory receptors – compounds involved in the chemical communication of insects. Functional characterization of the odorant-binding proteins has been initiated. Early evidence has shown that the co-evolution of insects and their viruses saw a co-dependency of the interacting proteins to initiate and establish infection in the host. Infectivity testing of the first mutants was completed in 2009-2010. These are the first steps in identifying candidates for potential release to control established pest populations.

Various NRCan projects work towards furthering our understanding of the relationship between forest pathogens and their hosts. In 2009-2010 NRCan researchers investigated 20 defence-related genes which show a high potential of playing a role in the Douglas fir defence response to pathogenic infection and another four genes which seem to be involved in pathogen resistance. These genes may become potential markers to be used in Douglas fir breeding and screening programs. Work continues in the molecular characterization of key signalling processes of poplar-rust interactions. Genes associated with rust resistance were identified by transcriptome analyses. Next steps include elucidating the potential role of these genes in poplar rust resistance. With continued collaboration with the USDA Forest Service and BC Ministry of Forest and Range, CFS researchers have developed a marker that allows the identification of resistant and susceptible western white pine seedlings following infection. Screening of partially resistant seedlings using single nucleotide polymorphism markers and genomic simple sequence repeat markers also continued in 2009-2010.

Research on genomics-based pest control products for species that are of economic importance involves searching for active ingredients, target sites, and new or improved strains for the development of environmentally benign pest control methods. The creation and analysis of cDNA libraries allowed scientists at NRCan to continue to work towards the development of molecular markers for the identification and monitoring of two economically important defoliating species (hemlock looper and white-marked tussock moth).

Identification of genes controlling desirable attributes in economically important tree species

The genomics program at NRCan-CFS directs research towards the development of methods, tools and databases for the discovery of genes in forest trees coding for attributes favouring fibre quality and forest sustainability: growth; wood quality characteristics; resistance to biotic and abiotic factors; and adaptation to environmental change. Work in 2009-2010 continued to explore and identify specific regions of the spruce genome coding for features such as adaptation to climate change and resistance to insect and diseases. For example, the evaluation of defence response and the importance of gene regulation in spruce trees were investigated by the production of transgenic white spruce trees with knockout genes. This will allow the development of selection tools, such as molecular markers, for tree breeders. CFS researchers performed and continue to perform experiments on select candidate genes to identify and validate these potential molecular markers.

Working towards the development of screening and selection tools for breeders, scientists at NRCan investigated a selection of candidate genes that are involved in growth and adaptation in spruce. Linkage mapping positioned 1800 single nucleotide polymorphism markers from gene coding sequences onto spruce genomics maps. Mapping bud phenology and growth traits continues to integrate data across environments and season to define robust quantitative trait loci. In addition, expression profiling studies identified 214 high priority genes for wood formation in white spruce from a list of a few thousand candidate genes. Identification of single nucleotide polymorphisms for these high priority genes is underway for the development of a genotyping array. A genotyping array for black spruce wood formation has already been completed and will be used in an association study with 480 trees.

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

In 2009-10 EC made significant advances in the application of the genomic tools and data that have been generated over the life span of the GRDI. Using GRDI funding, EC has developed and applied genomics tools related to the areas of risk assessment/management and wildlife conservation/management.

Risk Assessment/Management:

- Scientists discovered genes that could discriminate the effects of cadmium in high quality quantum dots (used in the development of nanoparticles) from dissolved cadmium in fish. The discovery of these genes provides important information on the mode of action of heavy metal containing nanoparticles and may help to explain how these substances may generate toxicity in aquatic organisms.
- Cost-effective in vitro methods were developed to screen for the effects of phenyl chloroformates on gene expression in avian embryonic liver, neuronal and heart cells. The data generated will be used under the Chemicals Management Plan to access and manage chemicals that are still on the market and have similar effects to chemicals already withdrawn from market due to toxicity issues.
- Research has been conducted assessing mercury impacts on loons. The information generated is being used under the Chemical Management Plan to conserve migratory birds and will assist in meeting obligations under the *Migratory Birds Convention Act*.
- Gene expression profiles on the effects of pesticides on aquatic life has been conducted. The profiles will be used as references against profiles resulting from exposure to field samples. The gene expression profiles resulting from field exposure will also be compared to the survivorship data obtained from in situ amphibian life-cycle observations.

Wildlife Conservation/Management:

- Twelve new species of parasites were discovered, as geographical and host ranges of sampling regions were expanded. Work is underway to create validated databases of species-specific gene sequences for parasite identification using standard national and international databases (GenBank and BOLD, the Barcode of Life database). In addition, morphological voucher specimens are being deposited at the Canadian

Museum of Nature. End-users will be able to collect and submit specimens of parasites to obtain species-level identifications of disease-causing organisms at minimal cost, without recourse to expert taxonomists.

- Riding Mountain National Park was identified as a stronghold for genetically pure Golden-winged Warblers using mitochondrial DNA. Preliminary results suggest that the population of Golden-winged Warblers in the Rainy River district of Ontario might also be free from genetic introgression.
- Using a combination of gene tacking and enzyme activity profiling, the commercial application of bacteria consortia was tracked. The study was performed in the context of urban effluents and provides evidence of the presence of microbial products. The next step is to trace the fate of commercial bacteria being released into effluents using the Montreal Wastewater treatment plant as a case study. A disinfection step will be applied at this plant to attempt to remove these bacteria from the environment.
- Work on the avian influenza virus in the Northwest Atlantic was conducted. Important discoveries include the fact that gulls in Newfoundland carry avian influenza viruses that contain both Eurasian and North American lineages. This result indicates that intercontinental mixing across the Atlantic occurs in wild birds, as seen in the Pacific. The second important finding suggest there may be marine-habitat related lineages of viruses in North America, whose role in global avian influenza dynamics is yet to be understood. Results also show that the prevalence of avian influenza virus is relatively low among seabirds, with fluctuations in the number of incidents occurring throughout the year. This finding is not consistent with what has been documented in waterfowl and may have implications for establishing the most appropriate times for any future surveillance efforts.

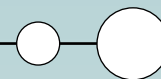
- New PCR screening tools were developed to identify *Pasteurella multocida* (small, gram-negative, non-motile, non-spore-forming bacteria) in avian and environmental samples, providing more rapid, less expensive, and more reliable results compared to traditional bacteriological methods. The new screening tools will enable identification of the proximate (carrier birds vs. environmental sources) and ultimate sources of the recent emergence of *P. multocida* strains causing outbreaks in Canada's eastern Arctic and east coast.
- Polymerase Chain Reaction primers have been developed to assess population genetic structures in the Pacific slope and Cordilleran forms of the western flycatcher.

In 2009-10 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 the US Environmental Protection Agency). Environment Canada is also working closely with the Organization for Economic Co-operation and Development and the International Programme on Chemical Safety of the World Health Organization in developing strategies and work plans to lead and coordinate international efforts for the application of toxicogenomic methods and approaches within a regulatory context. Strengthening of partnerships and joint projects between federal departments continues (e.g. Environment Canada and Fisheries and Oceans Canada).

Appendix A

Supplemental Performance Details

Annex 4 – R&D Outputs by Department



National Research Council Canada

- 79 publications in refereed journals
- 89 publications in refereed conference proceedings
- 70 invited presentations
- 23 technical reports
- 10 other publications (e.g. books and book chapters)
- 16 participation in national/international conferences, workshops, committees and networks
- 6 disclosures filed
- 7 patent applications
- 11 patents issued
- 2 licenses issued
- 6 material transfer agreements
- 4 peer-reviewed grants leveraged
- 80 collaborative agreements, including with OGDs, of which 15 are formal

Agriculture and Agri-Food Canada

- 54 publications in refereed journals
- 31 invited presentations (of which 16 international)
- 64 posters
- 10 book chapters
- 5 patents
- 3 agreements with external organizations

Health Canada

- 12 publications in refereed journals
- 23 presentations, of which 1 was invited
- 3 technical reports

Public Health Agency of Canada

- 6 publications in refereed journals
- 3 invited presentations
- 1 international conference presentation
- 6 formal collaborative agreements initiated and negotiated
- 1 genomics-related database developed and launched
- 4 bioinformatics programs rolled out
- 1 new bacterial genome annotation pipeline inaugurated
- 1000 Hepatitis C quasispecies genomes sequenced
- 1 quasispecies genome assembly algorithm prototyped
- 1 quasispecies sequence simulation program developed

Natural Resources Canada

- 22 publications in referred journals
- 5 publications in conference proceedings
- 26 invited presentations
- 1 book chapter
- 45 national conference presentations and posters
- 37 international conference presentations and posters
- Genomics related databases and libraries: numerous GenBank deposits (various insect pathogens, hemlock looper); development of arrays (white spruce, black spruce)

Environment Canada

- 22 publications in refereed journals
- 4 publications in refereed conference proceedings
- 1 invited presentation
- 8 other presentations
- Participants in 2 national networks
- Participants in 2 international committees

Fisheries and Oceans Canada

- 1 publication in refereed journals
- 4 invited presentations

Appendix A

Supplemental Performance Details

Annex 5 – Outreach by Department

National Research Council Canada

- Active external website and project wikis
- 10 citizen engagement activities – participation in science fairs, student mentorships, Sanofi-Aventis Biotech Challenge, etc.
- 2 community presentations and tours – canola field trial tours, S&T Day on the Hill
- Brochures created to promote the initiative

Agriculture and Agri-Food Canada

- Presentations in public schools
- Participation in science fairs

Health Canada

- Annual Health Canada Science Forum, with departmental and external invitees
- Research exchanges with other government departments

Public Health Agency of Canada

- 1 media interview
- 1 PHAC award

Natural Resources Canada

- 1 media interview
- 1 community presentation
- 4 web pages
- 3 factsheets

Environment Canada

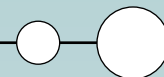
- Community presentations and tours conducted at GRDI participating institutes across Canada
- 2 web pages

Fisheries and Oceans Canada

- 1 media interview
- 1 community presentation

Appendix B

Genomics R&D Initiative: RMAF Overview



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 federal 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 and to ensure that genomics research adequately supports policy, regulatory, 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 continue. The hiring of highly qualified personnel (HQP), training of existing personnel, and provision of effective and efficient tools to enable research are essential components to successfully undertake research projects as well as be credible participants in genomics research and applications.

Research and Development – Research and development is the central component of this initiative. All activities surrounding the actual conduct of R&D, the transfer and adoption 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

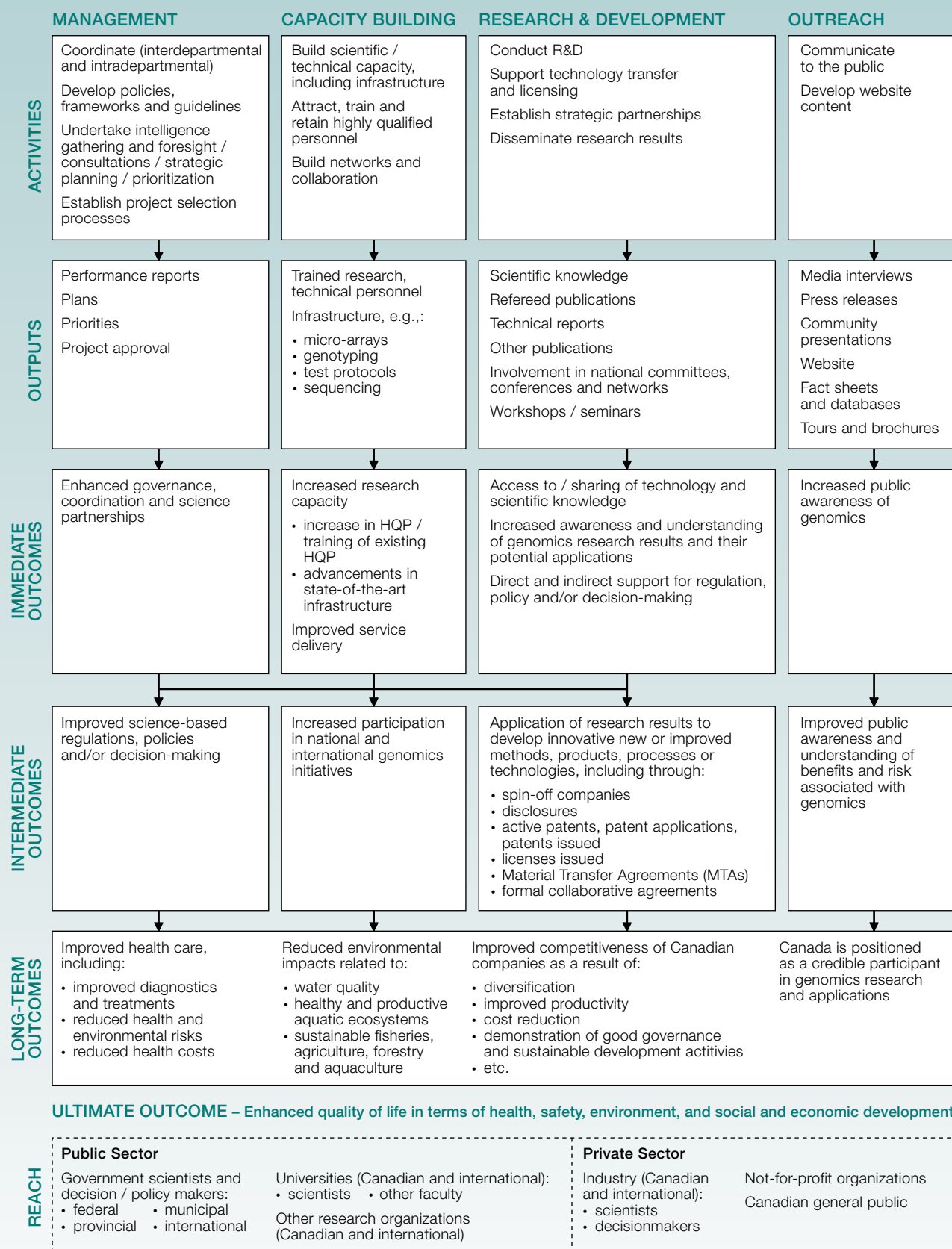


Table 5: Annual Performance Measurement Strategy

AREA	ONGOING INDICATORS	SOURCES	RESPONSIBILITY
IMMEDIATE OUTCOMES			
Enhanced governance, coordination and science partnerships	# of interdepartmental research initiatives (table summarizing initiative, scope, funding level, # of departments involved, description)	Project information	Departments
	# of partnerships / collaborations on projects by type, e.g.: <ul style="list-style-type: none"> • OGDs • universities • international organizations • private sector • Genome Canada • etc. 	Project information	Departments
	Internal funds 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"> • OGDs • universities • international organizations • private sector • Genome Canada • etc. 	Project information	Departments
Increased research capacity: <ul style="list-style-type: none"> • Increase in HQP / training of existing HQP 	# and type of new research personnel: <ul style="list-style-type: none"> • permanent and temporary (PDFs, students) • scientific and technical support 	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 GRDI funded projects (increasing expertise by doing research)	Departmental records	Departments
<ul style="list-style-type: none"> • advancements in state-of-the-art infrastructure 	Type of infrastructure: <ul style="list-style-type: none"> • acquired • adapted • upgraded • maintained 	Project reports	Departments
	\$ and % of allocation to infrastructure	Departmental records	Departments

AREA	ONGOING INDICATORS	SOURCES	RESPONSIBILITY
Access to and sharing of technology and scientific knowledge	<ul style="list-style-type: none"> # of papers in refereed journals (hard copy / electronic) information about journals available on request 	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 and 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
INTERMEDIATE OUTCOMES			
Increased participation in national and international genomics initiatives	Extent to which scientists in departments participate in other projects <ul style="list-style-type: none"> national vs international role on projects leveraging # of partners OGDs vs universities vs private sector vs Genome Canada vs others etc. 	Project information	Departments
	Other types of participation in national and international genomics initiatives <ul style="list-style-type: none"> number of initiatives types of initiatives role of departments / scientists 	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"> spin-off companies disclosures active patents, patent applications, patents issues licenses issued material transfer agreements (MTAs) formal collaborative agreements 	Description of application of research results (internal and external) and 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	ONGOING INDICATORS	SOURCES	RESPONSIBILITY
IMMEDIATE OUTCOMES			
Enhanced governance, coordination and science partnerships	Evidence of coordinated planning (interdepartmental and intra-departmental), priority setting and management approaches (e.g., GRDI ADM Coordinating Committee, GRDI Working Group, linkages to the Canadian Regulatory System for Biotechnology)	Minutes of meetings, decision records, planning documents, etc.	Departments GRDI ADM Coordinating Committee GRDI Working Group
	# of interdepartmental research initiatives (initiative, scope, funding, # 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">• OGDs• universities• international organizations• private sector• Genome Canada	Project information	Evaluators based on departmental information
	Internal funds leveraged: A-base and B-base funding	Departmental records	Evaluators based on departmental information
	Utilization of funds for intended purposes	Project information	Evaluators based on departmental information
	Other funding and in-kind contributions by type (complementary to previous information on collaborations), e.g.: <ul style="list-style-type: none">• OGDs• universities• international organizations• private sector• Genome Canada	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 departmental 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">• within departments• in other departments• in other levels of government• in other organizations	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">• within departments• in other departments• in other levels of government	Interviews with regulators, policy makers and other managers, review of decision records, discussion documents, White Papers	Evaluators based on departmental information

AREA	ONGOING INDICATORS	SOURCES	RESPONSIBILITY
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 departmental information
INTERMEDIATE OUTCOMES			
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"> • within departments • in other departments • in other levels of government 	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"> • national vs international • role on projects • leveraging • # of partners • OGDs vs universities vs private sector vs GC vs others. 	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"> • number and types of initiatives • role of departments / scientists 	Departmental records, interviews with dept reps / reps of other initiatives	Evaluators based on departmental information

AREA	ONGOING INDICATORS	SOURCES	RESPONSIBILITY
Application of research results to develop innovative new or improved methods, products, processes and technologies through: <ul style="list-style-type: none"> • spin-off companies • disclosures • active patents, patent applications, • licenses issued • Material Transfer Agreements • formal collaborative agreements 	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
LONG-TERM OUTCOMES			
Improved health care, including: <ul style="list-style-type: none"> • improved diagnostics and treatments • reduced health and environmental risks • reduced health costs 	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"> • water quality • healthy and productive aquatic ecosystems • sustainable fisheries, agriculture, forestry and aquaculture 	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"> • diversification • improved productivity • cost reduction • demonstration of good governance and sustainable development 	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
ULTIMATE OUTCOME			
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