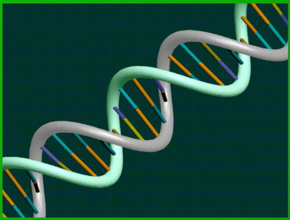
Sequencing the Salmon Genome



A Deliberative Public Consultation

Building a GE3LS Architecture & cGRASP

a Genome BC & Genome Canada Project

University of British Columbia

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Building a *GE^{3}LS* Architecture

Building a GE^{3}LS *Architecture* (*GE^{3}LS* Arch) is located at the W. Maurice Young Centre for Applied Ethics, College for Interdisciplinary Studies, UBC. The *GE^{3}LS* Arc uses consultation methods and computer-mediated technologies to understand 1) how people make decisions, and 2) their perspectives related to genomics research and biotechnology related to human health, food, and the environment.

More information is available at: http://gels.ethics.ubc.ca:8213/ge3ls-arch

Consortium for Genomics Research on all Salmonids Project (cGRASP)

consortium for Genomics Research on all Salmonids Project (cGRASP) is located at Simon Fraser University and the University of Victoria in British Columbia, and at the Centre for Integrative Genetics, Norway. The consortium was formed in 2005 to answer the need for a coordinating body to oversee research and ensure accessibility of new findings in the area of genomics tools for salmonid research.

More information is available at: http://www.cgrasp.org/

Face-to-Face and deliberative public consultation

The Face-to-Face (F2F) research team designs and tests methods to support public involvement in the ethical analysis of issues relating to biotechnology and genomics. A sub-project within the Genome BC/ Genome Canada-funded project *Building a GE^{3}LS Architecture*, F2F employs in-depth interviewing, focus groups, and deliberative engagement events to learn about and investigative social norms as they apply to complex scientific issues. The research team also supports training in F2F and deliberative democracy approaches. The F2F team has authored this document.

More information is available at: http://gels.ethics.ubc.ca:8213/ge3ls-arch/face-to-face

The purpose of this booklet

This booklet is meant to provide background information to support deliberation on the implications of sequencing the salmon genome. It contains perspectives on salmon collected from academic literature, the media, and interviews. While it includes a wide variety of opinions, it does not encompass the diversity of all possible perspectives. The hope is that it will stimulate discussion and reflection.

The importance of deliberative democratic discussion

People in our society are concerned about the development and regulation of science and technology. Deliberative democratic events shift the focus of discussions about these concerns from telling people what they need to know about science and technology, to recognizing that all citizens are sources of information and have important things to say about policy.

In this deliberative democratic event we hope to both educate and seek advice. Our intent is to inform policy more effectively by bringing together people from many different backgrounds, and with many different opinions and life experiences, encouraging them to work together on challenging issues. By using the knowledge, insight and advice of an educated citizenry to create policy, we can make decisions that reflect social realities and add to the trust we can put in the outcomes of these processes.

Words and their meanings

A word can have multiple interpretations and meanings. To avoid confusion, in this booklet:

- **wild salmon** refers either to salmon hatched in a natural freshwater environment and matured in the ocean, or to salmon hatched in hatcheries matured in the ocean.
- **farmed salmon** refers to salmon raised in captivity, first in tanks, and later in ocean net-pens.
- **transgenic salmon** refers to salmon that have foreign DNA inserted into their genomes to artificially change certain characteristics, such as growth rate or temperature tolerance.

A glossary of terms can be found at the end of the booklet.

Contents

Introduction: Deliberating On Sequencing Salmon........ 1
The Science........ 2
Sequencing the Genome........ 2
Sequencing the salmon Genome........ 2
The Fish: Contextual Issues........ 5
Salmon in British Columbia........ 5
Salmon and Our Economy........ 5
The Debate over Declining Salmon Stocks........ 6
Salmon and Conservation Genetics........ 6
Perspectives: The General Public........ 7
Salmon Genomics and the General Public........ 7
Salmon Genomics and Aboriginal Peoples........ 7
Salmon Genomics and Fishers........ 8
Perspectives: Industry........ 9
Salmon Genomics and Industry........ 9
Salmon Genomics and Aquaculture........ 9
Salmon Genomics and the Sport Fishing Industry........ 10
Foreign Companies, Canadian Companies........ 10
Salmon Genomics and the Restaurant and Food Industry........ 11
Perspectives: Regulators........ 12
Canadian Regulations on Genomic Technologies........ 12
The Role of the DFO........ 13
International Regulatory Bodies........ 14
Perspectives: The Environment........ 15
Overfishing........ 15
Habitat Loss........ 16
Competition and Disease........ 17
Perspectives: Consumers........ 18
Labeling........ 18
Perspectives: the Research Community........ 19
Towards a Knowledge Economy........ 19
Salmon Genomics and the Knowledge Economy........ 19
GLOSSARY........ 20

Introduction: Deliberating On Sequencing Salmon

Genome sequencing opens a world of possibilities for agriculture, environmental studies, and food production. By uncovering an organism's genetic information—its genome or entire complement of DNA—researchers can begin to better investigate its growth, health, reproduction, nutritional value, and role in the environment. Hundreds of organisms from around the world have and are being sequenced through efforts that will have practical effects on the environment and society.

Salmon—the common name for a variety of related fish species—is a good example through which to consider these effects. Culturally and economically important in BC and throughout the world, salmon have been fished, consumed, written about and made the subject of art, they have economic value, scientific intrigue and a symbolic history. They are, in fact, one of the most thoroughly studied fish on the planet, including decades of research to better understand their genetics. The field of salmon genomics has blossomed in the wake of this work and today both governments and industry invest in ongoing efforts to sequence the genomes of certain salmon species.

In many areas, conservation of declining wild salmon populations is increasingly important. Typically, growth in support for conservation is matched by a growing demand for salmon as food. Solving these conflicting demands will rely in large part on increasing our understanding of salmon, and sequencing the salmon genome may play an important part in gathering the necessary information. While some people believe that sequencing the genome is a good idea that should proceed, others urge a more cautious approach that first seeks to identify and understand the long-term consequences for the fish, the environment, and humans that may follow from this work.

Rules and regulations concerning how information derived from a salmon genome will be used are still evolving. As the significance of the knowledge gained becomes clearer, the public's environmental, economic, and ethical concerns will grow in importance.

Some governing bodies already take public involvement seriously, holding focus groups, online consultations and community dialogue sessions on topics such as animal biotechnology, the safety assessment of genetically modified (GM) foods, and wild salmon. While this is a good start, the scope of issues addressed through these efforts is limited and there is concern that public voices are not being heard on a wide range of issues surrounding biotechnology. The appropriate form of public involvement should include serious reflection on how decisions are made, what scope of issues should be addressed, and who should be involved in decision making. Informed deliberation happens when citizens understand each others' views and work together to suggest how to shape a common future.

The research team organizing this event does not believe that experts and elected officials have sufficient knowledge of the views and interests of the public to design sustainable and supportable policies on salmon genomics. With this in mind, this booklet is organized to provide a general introduction to the science of sequencing the salmon genome, the complex social and cultural issues surrounding salmon, and six perspectives on the implications of sequencing.

We hope that by respecting the differences among us, a diversity of other perspectives will be introduced by you, the participants.

The Science

Sequencing the Genome

A genome is the complete DNA content of an organism. DNA directs the development and function of living creatures. It is composed of four nucleotide bases, labelled A, T, C, and G, which when arranged into segments known as genes direct the production of proteins that carry out biological functions. Sequencing a genome is the process of determining the order of the nucleotides in the DNA of an organism.

The sequencing process is mostly done by machines (DNA sequencers). Scientists interpret the sequencing information to identify the location of genes within the genome, the nucleotides that make up these genes, the regions that turn genes on and off, and the long stretches of DNA that separate genes.

Identifying genes and their organization gives hints to their function, helping researchers understand how organisms work. A yeast genome was fully sequenced in 1996, a worm in 1998, and a fruit fly in 2000. In 2003, the Human Genome Project described the sequence of the human genome.

Many other genomes have now been sequenced and new sequencing projects continue to appear as increasingly sophisticated technologies makes sequencing easier, faster, and cheaper. The rapidly growing amount of information on genomes now has led many scientists to redirect their research to better understand and make use of the available genomic information.

Sequencing the Salmon Genome

Salmon genomics is a broad field of study aimed at better understanding the function of salmon genes. In Canada, researchers studying Atlantic salmon have produced genetic maps to help locate genes on chromosomes, large libraries of segments of Atlantic salmon chromosomes that can be replicated in bacteria (bacterial artificial chromosomes), and genetic markers that can be used to track traits (trait loci). These resources are important steps towards sequencing the salmon genome, since they lay the groundwork to assembling sequencing information into a representation of the genome in the correct way. They also have diverse applications (see p.8, Applications of Salmon Genomics).

With such resources, many people expect the Atlantic salmon genome to be sequenced soon . However, to date, there is no project in Canada, or any other country, aimed at sequencing the complete salmon genome (see sidebar).

Salmon Projects

Salmon are studied in a number of areas around the world.

consortium for Genomic Research on All Salmonids Project (cGRASP) Canada – Seeks to answer fundamental scientific questions about salmon in an effort to address conservation and environmental issues, and to assist commercial, sport, and aquaculture industries. Information it is developing could be used to enhance breeding programs to select desirable market traits for salmon

Salmon Genome Project (SGP) Norway – Works to increase available genomic information about Atlantic salmon biology. SGP has developed many tools, including genetic markers and gene maps.

Salmon Traits Scotland – Looked for salmon genes involved in traits important for salmon farming, including genes involved in metabolism, responses to infections, and seawater adaption. The project ended in February 2007.

Sequencing the salmon genome could help scientists understand the evolution of salmon, basic salmon biology, and salmon behaviour. For example, sequencing could:

- reveal the genes that determine the sex of a fish and characteristics such as growth, temperature tolerance, and disease resistance;
- contribute to conservation efforts by helping to breed and re-stock genetically-diverse, and therefore more resilient salmon;
- make aquaculture more sustainable by:
    - contributing to the development of DNA vaccines to treat and prevent disease in salmon. This (for example) could reduce the use of pesticides to treat sea lice infestations;
    - helping salmon digest alternative diets. This could decrease the costs of fishmeal fed to salmon, meal often made from feeder fish harvested in developing countries;
    - minimizing the negative environmental effects of salmon waste; and
- increase our understanding of the effects of changing environments and climate on salmon, suggesting ways in which these areas could be addressed.

A variety of concerns have been raised in connection with sequencing the salmon genome. For example, sequencing could:

- challenge indigenous ecological knowledge by gaining historical information on salmon that differs from aboriginal stories and "tinkers with the totem." Aboriginal and other cultural groups see Pacific salmon (in particular) as a totemic animal, signifying dependability and renewal;
- lead to the genetic modification of salmon. There are concerns that escaped modified salmon could affect wild salmon stocks and other aquatic organisms and their habitats, by out-competing wild salmon for nesting areas or food;
- increase research into transgenic salmon. While transgenic salmon created without sequencing the salmon genome already exist in laboratories, there are concerns that sequencing will make it easier for such salmon to be created and eventually marketed; and
- raise concerns about the ownership of the salmon genome. This leads to questions about how salmon genomics research will be funded and how to ensure long-term economic benefits for Canada.

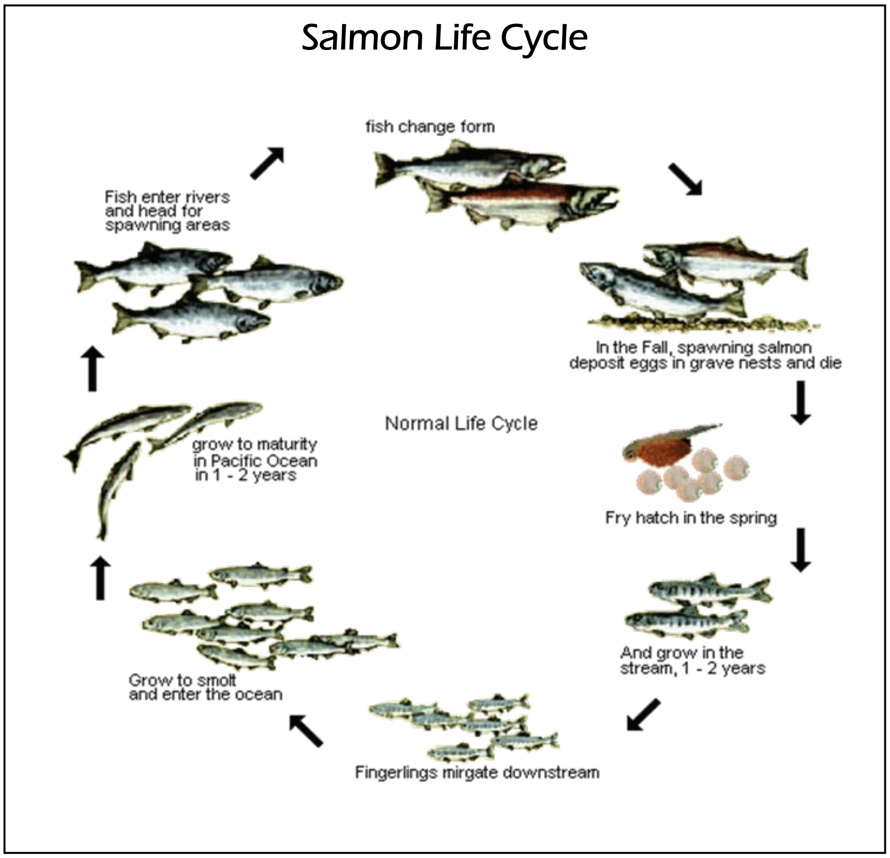
Applications of Salmon Genomics

Research Area	Application of Salmon Genomics
Evolutionary biology	Salmonids are one of the most primitive types of bony fish. If the Atlantic salmon genome sequence is available, it could become the salmonid reference allowing sequences of similar fish—for example, rainbow trout and charr—to be more easily determined.
Ecology	The salmon sequence will enable the identification and distinction of salmon populations based on genes that are selected for various environments, such as genes affecting temperature tolerance.
Physiology	The salmon genome sequence may enhance our understanding of the genes involved in the physiological responses to stress in salmon.
Genetics	The resources developed to study the salmon genome, such as chromosome libraries and microarrays, might be used for other genomics research.
Immunology	Information gained from sequencing the salmon genome may lead to new pharmacological treatments and drugs.
Toxicology	Salmon sequencing may enable a better understanding of the genes that play a role in response to toxic and chemical substances found in the environment.
Nutritional science	Salmon sequencing may enhance the nutritional value of salmon through greater knowledge of the genes responsible for production of omega-3 fatty acids.
Environmental science (conservation and management)	Salmon sequencing may help environmentalists use salmon as a "sentinel species" by monitoring the quality of the aquatic environment using salmon genes whose expression patterns are known to respond to specific toxins.

The Fish: Contextual Issues

Salmon in British Columbia

Salmon is the common name for several species of ray-finned fish, including salmon, trout, and char, belonging to the Salmonidae family. Two of the most well known are Pacific salmon, which in Canada are native to west coast waters, and Atlantic salmon found in the east. British Columbia's Pacific salmon are made up of five species: chinook, chum, coho, pink, and sockeye. Each is part of BC's heritage, with a particular significance in aboriginal tradition and culture. Each is also a source of food for animals and humans, a source of jobs for rural communities, and a source of income.

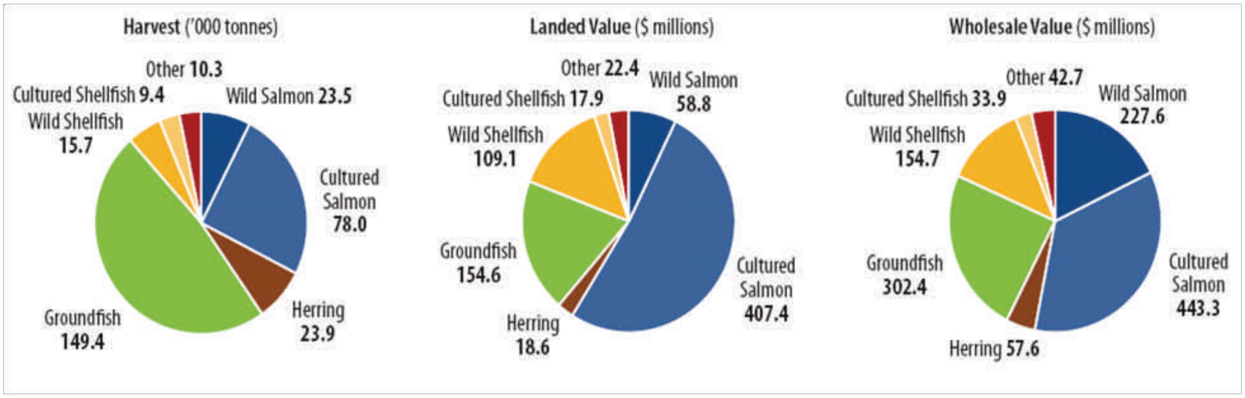


Salmon and Our Economy

There is an increasing demand for fish. The Food and Agriculture Organization (FAO) of the United Nations estimates that the global demand for fish could reach 186 million tonnes per year by 2030. However, in the 1990s, globally, commercial capture fisheries began to plateau at 80-100 million tonnes per year. The deficit between predicted demands for fish and the production of commercial capture fisheries has led to support for salmon aquaculture and efforts to replenish and protect wild salmon.

Currently Canada is the world's fourth largest producer of salmon following Norway, Chile, and Scotland: fish in Canada provide approximately 130,000 jobs in urban, rural and coastal regions. The wholesale value of all seafood processed in BC averages about $1.2 billion each year, with wild and farmed salmon accounting for approximately half of that total. In 2006, 23,500 tonnes of wild salmon valued at $58.8 million before processing (landed value) was harvested. In the same year, 78,000 tonnes of farmed salmon was harvested for a landed value of $407.4 million. Pen-raised Atlantic salmon comprise approximately 80% of farmed fish. Chinook and coho salmon, as well as steelhead trout, are also farmed in BC.

In Canada, the consumption rate of seafood is almost 10kg per person per year, less than one third the consumption rate of beef, pork, or poultry. BC supplies less than 10% of the total seafood consumed in Canada. BC also exports farmed salmon internationally to markets including the United States, Japan, and Taiwan.



The Debate over Declining Salmon Stocks

As early as the 1850s the effect of mining on salmon streams drew controversy. More recently, the reasons for declining wild salmon stocks have been hotly debated. Excessive fishing, various aquaculture practices, the degradation of salmon habitat, climate change, and diseases such as sea lice have all been pointed to as possible contributors. Resolving the issues and reversing the decline is a complex problem.

Salmon and Conservation Genetics

The conservation of different Pacific salmon species in BC is primarily concerned with the preservation, restoration, and protection of genetic diversity. Government programmes such as Canada's Policy for Conservation of Wild Pacific Salmon have been established to tailor techniques to accomplish these goals. Reductions in over-fishing, attempts to decrease the effects of salmon aquaculture, and the linking of the molecular identification of salmon stocks to opening and closing fisheries, are all part of current conversation efforts.

The 2003-2004 genetic management, i.e. molecular genetics for stock assessment, of the fisheries allowed for fulfilment of the US/Canada Pacific Salmon Treaty quotas without over-harvesting. The result was both the protection of the salmon population and increased fisheries revenue. In terms of reducing the negative genetic effects of aquaculture, the focus has been on the reduction of farm escapes. Mating between farmed and wild salmon threatens the unique genetic composition of both types of salmon. In light of this, efforts have been directed towards methods of sterilizing farmed fish through genetic manipulation, such as creating an all female monosex stock.

How sequencing the salmon genome will affect these options is open for discussion. The following chapters highlight some different perspectives.

Perspectives: The General Public

What are the implications of sequencing the salmon genome for the general public?

Salmon Genomics and the General Public

Salmon are part of our cultural past and present. They have a significant place in the cultural history of many non-aboriginal Canadians—for example, salmon were symbols of knowledge in the Celtic mythologies of Ireland—and are critically important in Canadian Aboriginal cultures. In fact, Aboriginal images are now part of a West Coast heritage of art, architecture and environment that is both recognized at home and exported to the world.

Salmon play a significant role in many economies. For example, in contemporary Scandinavian societies salmon are an important source of food, while in Alaska they form a major part of the economy. Concern over the salmon has provoked the government to establish the BC Salmonid Enhancement Program to counter declining stocks and fund habitat restoration projects, including spawning channels and hatcheries.

This diversity of relationships means that the societal impact of sequencing the salmon genome will vary across different groups and it will be hard to predict. For example: Will subsistence fishers benefit from genomic technologies used for species conservation, or will short-sighted application of knowledge about the salmon genome result in a less genetically diverse species incapable of withstanding environmental pressures?

Salmon Genomics and Aboriginal Peoples

The salmon is a totem symbol signifying "dependability and renewal—a provider" for indigenous tribes in the Pacific Northwest. It is a staple food, a catch depended on for subsistence and one used in traditional ceremonies by several Aboriginal peoples. Salmon is also economically important to Aboriginal citizens who participate in commercial fishing or who are involved in the fish processing or cannery industry. Almost one-third of commercial salmon fishers with salmon licences are Aboriginal and the largest single job source for BC's Aboriginal peoples is the fishing industry.

The Impact of Salmon on Aboriginal Peoples in BC

The Gitxsan and Wet'suet'en peoples of interior north-western BC celebrate the first salmon feast of the year by telling a story about salmon and the importance of respecting fish.

The 15 related nations that comprise the Nuu-chah-nulth peoples of coastal Vancouver Island associate the ripening of salmonberries with the return of adult sockeye salmon to freshwater. Several Aboriginal *adawx* (oral traditions) recount the history and relationships people held with animals, including salmon. Some of the stories warn that if people neglect to care for salmon, the species will become extinct.

Thousands of years ago, Sinixt villages lined the Kootenay, Solcan, and Columbia Rivers. Salmon was abundant and every season a designated "salmon chief" distributed the catch among the villages. Logging, European settlement and the eventual opening of the Grand Coulee Dam on the Columbia River in 1942 marked the end of this way of life. Food scarcity and dispersal of Sinixt bands resulted. The government of Canada declared the Sinixt extinct in 1956, but Sinixt members continue to declare their existence. The birth of Agnice Sophia Campbell in 2005 marked the first birth of a Sinixt baby on Sinixt territory in almost 100 years.

While the views of Aboriginal citizens towards salmon genomics are not extensively known, some have expressed opinions concerning the environment and conventional fish farming.

- Creation stories vary, but a belief common to many Canadian Aboriginal cultures is that humans are designed as stewards to protect "creation," including all animals. Some are concerned that interpretations of science may fail to respect traditional ecological knowledge and indigenous creation stories that support this belief, or challenge political rights.
- Science will benefit the rich. In the past, local communities in developing countries with the most abundant varieties of aquatic species were rarely compensated for the fish they provided for research. Instead, benefits of the knowledge and research tended to come to academics and fish breeders from developed countries. For example, tilapia from Egypt, Ghana, Kenya, and Senegal benefited communities in the Philippines, China, Thailand, and the southern US where samples were sent, and did not necessarily benefit the African communities that donated the fish. This has raised concerns over whether there should be some controls on research, including the use of genetic samples.
- Breeding or manipulating salmon (for example) for commercial purposes could limit its usefulness for traditional purposes (or encounter prohibitions). Salmon with a low fat content, for example, does not make good quality dried fish.

Some Aboriginal groups are actively supporting genomic work on the principle of preserving ecosystem health. The Nuu-chah-nulth, for example, have participated in genomic applications that are potentially beneficial to wild salmon, such as taking salmon DNA fingerprints and gene banking salmon stocks.

Salmon Genomics and Fishers

Sequencing the salmon genome may affect fishers or citizens associated with the fishing industry.

- Recreational or sport fishing for pleasure or competition: Recreational salmon fishing has the potential to generate substantial returns to the provincial economy and now almost equals the value from commercial fisheries. The health of this industry is dependent on a reliable stock of salmon. With many endangered salmon species, salmon genomics technologies might help reinforce conservation efforts.
- Commercial fisheries: Some communities in BC are economically dependent on commercial fishing. These communities could be devastated by the failure of a salmon run, especially if fishers do not have any other type of job training. Salmon genomics applied to conserve salmon runs might benefit these fishers.
- Aquaculture: This industry provides stable job opportunities without the travel associated with commercial fishing jobs. Applying salmon genomics to the aquaculture industry might provide some societal benefits, such as less pharmaceuticals used to produce healthy salmon available for consumption. However, some environmental NGOs oppose salmon farms, citing harms to the environment, health concerns, and exploitation of poor countries where fish feed is acquired.

Beyond the affect of salmon genomics on people employed in these industries, there is also an impact on each industry as a whole. This is discussed in more detail in the next section.

Perspectives: Industry

What are the implications of sequencing the salmon genome for industry?

Salmon Genomics and Industry

Sequencing the salmon genome may affect the salmon industry, including the local food industry, foreign companies, researchers, biotechnology companies and the fishing industry (commercial fishing, aquaculture, sport fishing and tourism). Some members of the salmon industry state that sequencing could decrease the cost of salmon while increasing salmon availability and welfare. Others worry that salmon industries are motivated by financial gains and do not pay enough attention to environmental and cultural concerns.

Salmon Genomics and Aquaculture

Aquaculture often tops the list in discussions of genetic biotechnologies and sequencing the salmon genome. Supporters argue that sequencing the salmon genome will improve breeding and rearing practices to enhance salmon growth rates, flesh quality, disease resistance, the production of single sex fish (female salmon grow faster than male salmon), and enable fish to eat less expensive diets. A sequenced genome may also help scientists better understand how environmental conditions such as day length, water temperature and current influence salmon growth and breeding. This could help salmon farmers increase the tolerance of fish to environmental changes and overcome reproductive difficulties linked to the environment, thereby helping ensure a steady supply of salmon.

It is not difficult to imagine that such changes could be economically beneficial to the aquaculture industry in both BC and Canada in terms of increasing output and reducing costs. Coastal communities may also benefit. If aquaculture profitably expands these communities would see an increase in jobs and a less transient source of income than logging or fishing, thereby creating a more stable population.

However, aquaculture is a controversial topic in BC and around the world. The controversies include the negative effect of salmon farms on the environment (e.g., escapements, pollution, fish disease), their effect on human health from the medications used to treat disease in farmed fish, and jurisdictional issues, particularly

The *AquAdvantage™* salmon

Aqua Bounty Technologies Inc. is a U.S. company that focuses on improving productivity in commercial aquaculture. The company created the AquAdvantage salmon, a genetically modified breed of salmon that grows faster than traditional farmed salmon. They did this by altering a growth hormone gene in Atlantic salmon. In normal salmon the hormone gene is controlled by light, so salmon only grow during the summer months. By introducing part of a gene from the ocean pout (a fish found in the North West Atlantic) the company was able to keep the growth hormone active all year round.

Aqua Bounty claims these fish reach market size in half the time of regular farmed salmon and that they convert feed into body mass 10-30% more efficiently. The fish therefore grows faster, but not bigger. The company says the fish won't look or taste different than other farmed salmon, and that they will cut farm costs by 35%. They also claim AquAdvantage salmon will produce less waste, won't interbreed with wild salmon if they escape (they are neutered), and can be farmed inland to avoid ocean pens. Aqua Bounty is negotiating with the U.S. FDA to obtain approval to market these salmon.

It is important to note that the AquAdvantage salmon was produced without a full salmon genome being available. While related, the issue of transgenic salmon is thus separate from the project of sequencing the salmon genome.

in the context of First Nations claims. That said, it should be noted that the sequencing itself will not necessarily lead to applications in aquaculture, and could identify and reduce some of the harms.

Salmon Genomics and the Sport Fishing Industry

Some people argue that sequencing the salmon genome would be beneficial for sport fishing in BC and Canada. They believe that sequencing would increase the availability of wild salmon through a number of mechanisms. For example, an increase in aquaculture through the use of genomics (see above) could lead to a decrease in reliance on commercial wild salmon fishing, thereby leaving more wild salmon for sport fishing. Others argue that a better understanding of salmon genomics will help conserve and enhance wild populations through hatcheries, again leading to more wild salmon for sport fishing.

Foreign Companies, Canadian Companies

There is a large foreign influence on the Canadian salmon industry through the domination of the wild and farmed salmon market by Norway and the United Kingdom. Norway in particular plays a strong part in directing research on Atlantic salmon towards aquaculture: Norwegian researchers are currently working on sequencing the Atlantic salmon genome. The Norwegian dominance of the aquaculture industry means that the majority of aquaculture in BC is owned by foreign companies.

The predominance of a few aquaculture firms is seen all over the world with 40% of farmed salmon being produced by seven firms. Some groups fear that this means that research and development of applications involving salmon genomics will focus on how to enhance commercially and economically important traits relevant to aquaculture, instead of focussing on other research topics such as conservation and enhancement of wild stocks.

Foreign industry dominance also raises the question of who benefits from the results of the salmon genomics research. A number of non-governmental organizations have voiced concerns that BC may be used as a laboratory, while the economic benefits from the research would go to foreign companies rather than indigenous communities and the province.

Salmon Biotechnology and Pharmaceutical Drugs

Pharmaceutical companies have long been interested in studying marine species in the hopes of finding new medications and drugs. Examples of their successes include a drug called protamine sulphate that comes from salmon sperm. Protamine sulphate is used to treat people who have had a heparin overdose and are at risk of haemorrhage.

Another example is the hormone calcitonin extracted from salmon and used as a nasal spray to treat osteoporosis. Pharmaceutical companies interested in the use of marine species may gain further information from sequencing the salmon genome, leading to other treatments and drugs. Research from salmon genome sequencing may also have applications for biotechnology companies. For example, researchers recently used DNA from salmon sperm to improve LEDs (light emitting devices) by increasing their brightness, energy efficiency and lasting time.

Salmon Genomics and the Restaurant and Food Industry

Sequencing the salmon genome may have a number of consequences for the restaurant and food industry. For example, sequencing the genome may increase the availability of farmed salmon, which may lower its price. Some predict half the salmon consumed by 2020 will be farmed. As the global demand for fish increases, the potential for salmon that grow faster and cost less may satisfy this need.

There is also the possibility that sequencing the salmon genome may help create an enhanced product. For example, the colour of salmon flesh is viewed by many as an important marker of quality and taste. Wild salmon develop pink flesh from a diet containing a naturally occurring pigment called Astaxanthin. Currently, farmed salmon are fed synthetic Astaxanthin to achieve the pink flesh of wild salmon. Fisheries and Oceans Canada (DFO) is researching genes involved in the flesh color of salmon, which may enable breeding or modification to create pinker flesh without the need for artificial Astaxanthin.

At the same time, there is concern that there could be a consumer backlash if GM salmon are more widely developed, due to concerns over the effect on the environment, human health, and the ethics of modifying living organisms. There is a danger that the mere possibility of salmon being modified could taint the entire salmon industry, thereby leading to public shunning of the fish in general. In 2002, when *AquAdvantage™* salmon (see sidebar pp.13) was reported in the media, over 200 chefs, supermarkets and seafood distributors in over 40 different states in the US signed a petition saying they would not serve any genetically modified fish.

Genetic Modification

While genetic sequencing is *not* genetic modification, the knowledge so derived could possibly facilitate the development of genetically modified and transgenic salmon, which pose unknown risks to the environment.

GM food is a complex issue; some countries such as the United States and Canada regularly consume crops and foods that contain genetically modified products; public pressure in Europe led to a backlash against GM foods resulting in, among other things, stringent labeling. Some GM fish, such as tilapia, are available and readily consumed in countries from China to the Philippines to Cuba. How a GM salmon would be viewed by the Canadian public is unclear.

Perspectives: Regulators

What are the implications of sequencing the salmon genome for regulators?

Canadian Regulations on Genomic Technologies

The official policy of the Canadian government is to support the growing biotechnology industry while ensuring public and environmental health and safety. There are no regulations in Canada, or at the international level, designed to specifically address salmon genomics.

Like many other novel technologies, salmon genomics is managed through a complex web of rules and regulations. That said, there are regulations in place to guide genomic technologies; it is likely that any future regulations concerning salmon genomics will follow a similar path.

In the U.S., many different agencies have the legislated ability to regulate genomic technologies; however, only the Food and Drug Administration (FDA) has taken on this authority. The policy of the FDA is to regulate food, feed, food additives, and veterinary drugs to determine if they are safe to eat. Some experts and the public are concerned that the FDA alone is not capable of considering issues beyond its mandate such as the environmental, social, and ethical aspects of novel technologies.

In Canada, more government bodies are involved in assessing and regulating genomic technologies including DFO, Health Canada, the Canadian Food Inspection Agency, and Environment Canada. As in the US, these bodies follow the principle of substantial equivalence. If a genomic technology does not fall under any regulations, it is covered by the "safety net" of the Environmental Protection Act. However, this act has been criticized by the Royal Society of Canada's Expert Panel on the Future of Food Biotechnology for failing to require research into the impacts of genomic technology on conservation or biodiversity.

One key for regulators looking to the future of salmon genomics is that it will have implications on local, regional, national, and global levels, likely resulting in fragmented decision-making, and regulatory overlaps and gaps. For example, salmon will cross national boundaries during their natural life cycles, bringing with them the results of genomics research and applications, yet there is no joint US-Canadian institution to regulate salmon genomics.

Decisions about Genomic Technologies and the Use of Substantial Equivalence

In both the US and Canada, decisions to approve the use of genomic technologies are often based on assessing whether a genomic technology or product is similar to the conventional variety from which it has been derived. In other words, regulators are trying to determine if the two products can be considered "substantially equivalent." Currently, a decision on substantial equivalence is seen as a declaration of safety—once established, the genomic technology is likely to be approved, even if genes are introduced through mutation or crossing with other species.

Advisory bodies have suggested using substantial equivalence as a guiding principle alongside rigorous scientific assessment. The Canadian government agrees and in 2001 promised to revise their Guidelines for the Safety Assessment of Novel Foods accordingly.

The Role of DFO

DFO is the lead federal agency for regulating salmon aquaculture and will likely be involved in regulating salmon genomics. Currently, DFO is actively involved in salmonid research, operating a salmon gene banking program for wild salmon conservation, participating in the development of biotechnologies, and studying transgenic fish.

DFO draws its power and mandate from the Department of Fisheries and Oceans Act and from many other different regulations and acts such as the Fisheries Act. Created in 1868, the Fisheries Act encompasses all marine organism fisheries and culturing, pollution and marine habitat protection, and fish health.

> *The Fisheries Act is one of the most important pieces of legislation for managing aquatic resources in Canada. The fish habitat provisions of this Act enable the federal government to protect marine and freshwater habitats supporting those species that sustain fisheries, namely fish, shellfish, crustaceans and marine mammals. -DFO, 2007*

Critics argue that DFO's mandate should not be stretched to advocate for or regulate new industries like aquaculture and new technologies like salmon genomics. They state that DFO's main responsibility is to maintain and promote the health of wild fish stocks. Conservation organizations see protecting wild salmon and advocating for aquaculture and technologies as contradictory. This is because they see wild salmon stocks as threatened by new industries like salmon aquaculture through disease, competition, and other risks. DFO responds to these concerns by stating that salmon aquaculture will reduce the pressure on wild fish stocks and enhance wild fisheries over time. They are also actively involved in research into the environmental impacts of salmon aquaculture.

Others have voiced concerns that the Fisheries Act is poorly adapted to regulate industries such as aquaculture. They point out that comparing aquaculture and fisheries is similar to equating crop agriculture with traditional hunting and gathering, arguing that the Act should not be stretched to cover topics that the document was not intended to cover when initially drafted.

In contrast, supporters argue that the DFO needs this regulatory expertise because DFO will eventually be the body evaluating risks if, for example, an application for transgenic salmon is submitted. DFO is currently in the process of developing new regulations for transgenic fish that will eventually be included under the Fisheries Act.

International Regulatory Bodies

Currently there are no international bodies or agreements dealing specifically with salmon genomics. Various UN bodies address issues of fisheries, sustainability, aquatic biodiversity, food, and agriculture. Other international bodies evaluate the affect of aquaculture, emphasize the conservation of salmon species, and support the aquaculture industry. International agreements originating from these bodies are usually not binding and can encounter problems in implementation at the national level. Regardless, international regulation is important because salmon are international by nature.

One international article that provides guidelines for future regulations concerning salmon genomics is the Convention on Biological Diversity (CBD), signed by 188 countries, including Canada, but not the US In 2000, member countries of the CBD signed the *Cartagena Protocol on Biosafety*, protecting biodiversity from the potential risks associated with modern biotechnology.

The CBD provides guidelines for national regulations on the conservation of biological diversity, sustainability, and the use of genetic resources in a fair and equitable way. These include:

- developing programs to support the expansion of sustainable fisheries livelihood;
- actively promoting the co-management of aquatic ecosystems and resources between governments and traditional communities; and
- collecting and storing genetic material, such as fish sperm or whole fish, in gene banks to guard against extinction and preserve material until science is ready/able to use it.

In Canada, one relevant section of the CBD concerns community resources. Under current international pressures, developing countries often hand over traditional knowledge for use or patenting with the promise that, in return, improved opportunities for trade will provide them with a greater economic advantage. However, it is important that indigenous communities have fully consented to this process and will benefit fairly from sharing this valuable knowledge with others. In response to this concern, the CBD recommends that countries acquire the informed consent of communities to use genetic resources while adhering to their practices, policies and laws. This is relevant in Canada, where many collections of salmon genetic material may belong to First Nations groups.

Perspectives: The Environment

What are the implications of sequencing the salmon genome for the environment?

Salmon are essential to the ecological health of the North Pacific. Having evolved alongside other species for thousands of years, salmon have become highly adapted to the region's ecosystems, while many other creatures – including humans – have come to depend on salmon for their survival and wellbeing. Over 100 different species depend on salmon for food, including orcas, bears, wolves, eagles and otters. In addition, salmon provide nutrients, such as nitrogen and phosphorous, to the surrounding forests when their carcasses are dragged into the woods by bears and other animals. Salmon are so highly integrated into the region's coastal systems that they are considered to be a keystone species.

Salmon are also considered to be an indicator species in that their health indicates the overall health of the ecosystem. When salmon numbers drop, it might be an indication that there is something wrong with their habitat and the wider ecosystem of which it is a part. In fact, there have been major declines in salmon numbers over the past 150 years, particularly in the southern half of the Pacific Salmon's range (the western American states), but also in British Columbia. Many individual stocks may have become extinct or are at risk of extinction.

The reasons for salmon declines are complex, but are generally tied to overfishing, habitat destruction, competition, and disease. Salmon genomics cannot solve these problems, but it may help inform solutions by helping us to better understand the evolution, biology, behaviour of salmon. In particular, it can help to identify stocks in need of conservation measures to help guide management and conservation plans; shed light on the genetic basis for adaptation to varying environments; and, identify the genetic risk factors for disease.

Overfishing

Salmon populations have declined as a direct result of overfishing. Fishing pressure began in the mid- to late-1800s with the development of powerful fishing techniques and canning technologies. By the early 1900s, the population of many stocks was reduced to unsustainable levels and some stocks probably became extinct. During the 20th century, pressure on stocks increased, as commercial, recreational and aboriginal fisheries demanded high harvest levels. Moreover, while overfishing reduces salmon populations overall, particular fishing practices can have a more specific impact on individual runs. Mixed-stock fisheries – which may target a particular stock of salmon but also capture other stocks that are mixed in with them – can threaten the continued existence of smaller stocks.

Salmon genomics cannot change fishing practices, but it may aid efforts to rebuild salmon stocks by conducting research into areas such as growth rates, the causes of mortality and genetic fitness. These findings could be used to reform hatchery practices, helping to enhance and augment wild salmon populations. Additionally, salmon genomics can be used to identify specific stocks of salmon, through, for example, genetic barcoding. In turn, this could help managers identify stocks in need of conservation measures and help inform DFO's decision of which salmon runs and stocks to open and close to fisheries.

Habitat Loss

Overfishing directly affects salmon populations, but there are also indirect threats. One of the most important is habitat destruction. In rivers and streams, salmon are dependent on cool, clear water with plenty of oxygen, clean spawning gravel, adequate nutrients and insects, resting and hiding places, and proper water flow. Over the years, a number of practices – including forestry, mining, agriculture, power generation and urbanization – have destroyed or degraded stream habitat. For example, forestry that cuts trees right to the stream bank results in warmer water with less oxygen, poor spawning beds, water flows that change the location of resting pools, and a more hostile environment for developing smolts. Affects such as these act as stressors to spawning salmon and their young.

Salmon genomics may address issues such as these by investigating the genetic basis for adaptation to varying environments, including the ability of salmon to respond to environmental stressors. Salmon found to be better able to resist these kinds of stressors could be developed and reared in hatcheries.

Streams are not the only habitat for salmon: they spend most of their lives in the ocean, where they gain over 95% of their biomass. Ocean conditions such as temperature, food availability, predators and disease agents can affect populations. While it may seem that people have little influence over conditions such as these, they may all possibly be impacted by global climate change.

For example, salmon on the Yukon River have been found to be infected with a disease (a parasite called Ichthyophonus) that is associated with warmer temperatures, while mackerel (which compete with and prey on juvenile salmon) have moved into BC waters. Climate change also affects river and stream habitats. For example, the disastrous 2004 Fraser River sockeye run, in which more than a million fish were "missing," has been blamed in part on high water temperatures.

Salmon genomics is not going to be able to mitigate climate change. However, it may help in processes for monitoring and adaptation. By studying how salmon are adapted to their environments, salmon genomics may aid in pointing to some of the risks associated with climate change. Microarrays, for example, enable researchers to identify patterns of gene expression in response to environmental changes. As the environment changes, salmon are affected and, in this respect, can be used as an indicator species for climate change.

Competition and Disease

Dwindling salmon stocks can be rebuilt through artificial rearing of salmon in hatcheries. In addition, pressure can be taken off of wild stocks by rearing salmon through the lifecycle until they reach marketable size. However, these two practices – enhancement and farming – carry risks. Enhancement –raising salmon eggs, smolts and fry to be released into streams and rivers in order to augment natural stocks – were first experimented with in the late 1800s. Today, a large percentage of spawning salmon have been hatchery raised. In the Columbia River, for example, 80% of approximately 1 million returning salmon are hatchery raised. One concern with salmon enhancement is that hatchery salmon are less successful in surviving and reproducing when compared with wild salmon. Another concern is that hatchery salmon interbreed with wild salmon, resulting in genetic dilution and less hardy offspring.

Salmon genomics may help to address these concerns by learning how wild salmon are adapted to their environments. With this knowledge, hatcheries could be reformed to produce salmon as adapted to local conditions as wild salmon, and more likely to survive and reproduce. In addition, salmon genomics could lead to new methods of monitoring and assessing interactions between hatchery and wild salmon to better address the potential for negative effects.

In contrast to enhancement, salmon farming is a commercial endeavour that involves growing and rearing salmon throughout their entire life course. While farmed salmon are not intentionally released into the environment, escapes sometimes do occur, prompting concerns similar to those associated with hatchery salmon.

There are other concerns more specific to the salmon farms. Farmed salmon live in close quarters and are more likely to spread disease and parasites (e.g., sea lice can jump from farm to wild salmon smolts, affecting chances for survival). Antibiotics and pesticides have to be applied, which pose threats both to human consumers and to the aquatic environment. Salmon farms also create fish waste which impacts the sea floor and shellfish. Lastly, since salmon are meat-eaters, feed for farmed salmon requires many tons of feeder fish, removing this source of protein from global ecosystems and humans that depend on them.

Salmon genomics may address issues of disease by identifying the genetic risk factors for disease and by developing DNA vaccines, thereby reducing the need for antibiotics and pesticides, as well as the likelihood that disease will be spread to wild stocks. With respect to escapes and interbreeding, salmon genomics can help develop ways to genetically sterilize farmed salmon, so that they are unable to reproduce even if they do escape. Finally, salmon genomics could help to deal with issues around feed and waste by contributing to the development of salmon that can digest different foods efficiently, thus reducing dependence on feeder fish and reducing overall fish waste.

DNA Vaccines

Disease affects both wild and farmed fish. Disease can wipe-out entire stocks and lower productivity and profitability in all fishing industries. In farmed fish, diseases caused by bacteria are treated with antibiotics that are added either to food or directly to the water. Excess antibiotics pollute the environment. Bacterial vaccines reduce the rate of disease and the dependency on antibiotics. Sequencing the salmon genome could provide information to help develop rapid and simple tests to identify disease and more effective ways to treat and prevent outbreaks. For example, DNA vaccines against viral disease are inexpensive and easy-to-produce, but require further research because they are difficult to administer and their effects on fish, the environment, and humans are not fully understood.

Perspectives: Consumers

What are the implications of sequencing the salmon genome for consumers?

There are now over 80 GM foods approved for sale in Canada including, varieties of canola, soybeans, and potatoes. Foods subjected to genetic modification undergo a food safety and nutrition assessment in Canada before they are approved for sale to consumers. Possible risks assessed before approval include the food's potential to cause allergic reactions and produce new toxins.

The assessment looks for differences between the GM food and its historically-safe non-GM counterpart. GM products are considered safe to eat if they are substantially equivalent to their non-GM counterparts (see sidebar: Substantial Equivalence). Currently there are no mandatory Canadian standards for labeling GM food products or for products from animals that have consumed GM feed.

Sequencing the salmon genome may lead to a range of applications, including GM salmon and GM salmon feeds. However, sequencing the salmon genome does <u>not</u> imply that GM salmon or salmon feeds will be created; many scientists involved in sequencing have no interest in genetic modification. Furthermore, a transgenic salmon (see sidebar: *AquAdvantage™* salmon) has already been created without the genome sequencing information . While some wonder if sequencing will enable additional GM applications, others worry that transgenic salmon are wrongly conflated with salmon genomics.

With these cautions in mind, consumer preferences will likely drive consumer-related applications of salmon genomics, which may have important implications for Canadians. Thus, although GM salmon is not a direct consequence of sequencing the salmon genome, it is one potential application that needs to be considered.

Labeling

"Labeling" is often a discussion surrounding GM products. There are currently no mandatory Canadian standards for labeling GM food products, or for products from animals that have consumed GM feeds. Some argue that labels are a source of consumer empowerment because they promote informed decision making, helping consumers avoid food allergens or foods that are inappropriate for religious, cultural, or other reasons. Consumers may also use information contained in labels to choose particular foods, food processing or farming techniques of which they approve (for example organic foods, vegetarian foods). Some also argue that sharing information through labeling promotes transparency and trust between industry and consumers.

Yet labeling involves important tradeoffs. It is possible that mandatory or voluntary labeling of food products will be an expensive process, a cost that would likely be passed back to consumers. It is sometimes assumed that more information is always better but there is limited space available on a label. Some information must be excluded. Additional information on labels could be a source of confusion for consumers if they do not understand how to use it.

To determine if these tradeoffs are worthwhile, we must also be sure that labeling will meet its desired goals of promoting trust and consumer empowerment. Consumer empowerment will only occur if consumers can afford the range of options. Some may not want to consume GM foods, but may not be able to afford non-GM foods. While labeling may increase trust for some, it may reduce it for others.

Perspectives: the Research Community

What are the implications of sequencing the salmon genome for the research community?

Towards a Knowledge Economy

Canada's economy has long been based on resource development, in most cases through the support of the government. However, in the last few years, resource intensive industries have become the focus of intensive scrutiny as people become critical of potential environmental impact.

The national economy still relies heavily on resources, while the developed world has begun to migrate away from basic industries like manufacturing and forestry to a knowledge economy. In this setting, technology and the knowledge behind it create value and jobs to propel economic growth and social development.

Such a knowledge economy is based on research and development that is carried out at universities and research institutions with public funding. While objectives like higher health standards and cleaner environment are usually linked to such research, for corporations, the main driver is to create new products and services that are profitable and unique.

Salmon Genomics and the Knowledge Economy

In the past 30 years, new technologies in molecular biology and information technology have supported rapid growth in genomics and its applications. Canadian universities and public research institutions have benefited financially and academically from this trend. Approximately $750 million was allocated to biotech research in 2004, producing almost 17,000 new products and services. Annual revenue from this work is close to $ 4 billion.

That said, such research is full of risks. Big investment does not necessarily mean good quality science and may not bring commercial products or social goods and when coupled with persistent social inequities such as homelessness and mental illness, these concerns can make research a "hard sell." In the end, even good technologies do not always make it to market, as international regulations impose strict limits on the commercial use of products. For the research community this must be viewed against the scientific prestige and technological advancement that sequencing the salmon genome could offer.

GLOSSARY

Atlantic salmon: A species of fish from the family *Salmonidae* originally found in the northern Atlantic Ocean.

Aquaculture: Farming of fish, shellfish or aquatic plants in fresh or salt water.

Biodiversity: Number and types of organisms in a region or environment, including both diversity in species and genetics within species.

Canadian Biotechnology Advisory Committee (CBAC): Committee created by the Canadian government to give policy advice on issues related to biotechnology.

Canadian Food Inspection Agency (CFIA): Agency dedicated to safeguarding food, animals and plants for Canadians. Responsible for applying policies and enforcing regulations.

Commercial fishing: Catching fish to be sold in the market place for economic profit (as distinct from sport or recreational fishing).

DFO: Fisheries and Oceans Canada. On behalf of the Government of Canada, DFO is responsible for developing and implementing policies and programs in support of Canada's scientific, ecological, social and economic interests in oceans and fresh waters.

DNA barcoding: Using genetic information to create a "barcode" capable of precisely identifying a species.

DNA fingerprints/DNA profile: The unique sequence of DNA bases in the genome of an individual organism.

DNA vaccines: Genetic information injected into an organism to create an immune response.

Farmed salmon: Salmon that have been raised in captivity, first in tanks and then in ocean net pens, and typically grown for human consumption.

Food security: Refers to the availability of food in a given region and access to it.

Genetic resources: Genetic material and information that has the potential to be used for research or the development of a product.

Genetically engineered: An organism that has had its genetic material altered through any method, including conventional breeding.

Genetically modified (GM): An organism, including products meant for human consumption, whose genetic composition has been altered through genetic engineering (a *GMO* is a genetically modified organism)

Genome sequencing: Determining the exact order of nucleotides in the genome of an organism.

Genome: The complete DNA content of an organism.

Genomics: The study of genes and their function, and their interaction with each other, the organism and environment.

Indicator species: Species whose health indicates the overall health of the ecosystem.

Keystone species: Species that plays a fundamental role in a community or ecosystem.

Knowledge economy: Term used to describe the world economy, where knowledge is seen as the main currency and driver for growth (contrasted to previous eras where either natural resources, cheap labor or industry where the key assets of the economy).

Landed value: The price paid to commercial fishers and/or aquaculturists for whole fish.

Microarrays: Microscope slides with thousands of unique DNA sequences on them originating from the genome of an organism of interest.

Nucleotide: The building block of DNA and RNA.

Pacific salmon: A species of fish from the family *Salmonidae* that is naturally in the Pacific Ocean. There are five genetically-distinct species of Pacific salmon in BC: chinook, chum, coho, pink, and sockeye.

Precautionary principle: Where there is high uncertainty concerning the level of risk, the proposed action or decision must be demonstrated to produce no harm: safety is not assumed, but must be established.

Recreational/sport fishing: Fishing for pleasure or competition.

Regulatory frameworks: Government rules governing an industry with the aim of protecting consumers, environment, workers and national industry.

Salmon genomics: The study of genes and their function, specifically related to salmon species. It includes the building of research tools to further this exploration.

Sea lice: A stinging larvae found in the ocean.

Substantially equivalent: A measure for assessing the safety of genetically modified organisms and whether a genetically modified product has the same characteristics as the conventional product, except for the novel trait.

Totem: An object such a plant or animal revered by certain individuals or social groups.

Transgenic salmon: Salmon that have been modified by inserting genes from the same organism or from another, unrelated, organism into their genome.

Wholesale value: The value of fish after processing, with all of the BC harvest included in the wholesale value as well as any fish imported from outside BC that has undergone processing within the province.

Wild salmon: Salmon either hatched in the natural environment, or hatched in hatcheries and released into the natural environment.