AN UNPRECEDENTED TRANSDISCIPLINARY STRATEGY

With funding of $98 million over seven years by the Canada First Research Excellence Fund, the Sentinel North Strategy allows Université Laval to draw on over a half-century of northern and optics/photonics research to develop innovative new technology and improve our understanding of the northern environment and its impact on human beings and their health.

Sentinel North is built around a major transdisciplinary research program to create new international mixed research units and research chairs, recruit world-class professors, and train the next generation of researchers capable of solving the complex problems of a changing North.

This ambitious transdisciplinary research program is founded on three major Thematic projects that foster technological innovation, especially in the field of optics-photonics.

Sentinel North is made possible, in part, thanks to funding from Canada First Research Excellence Fund.

THEMATIC PROJECT 1

COMPLEX SYSTEMS : STRUCTURE, FUNCTION AND INTERRELATIONSHIPS IN THE NORTH

The North, with its various interconnected networks, is a vast and complex system currently undergoing rapid climatic, ecological, social and economic changes. The main objective of this Thematic project is to acquire a better understanding of the complex systems of the North (microbiomes, ecosystems, geosystems and societies), their internal logic and their mutual interactions. The components of complex systems are linked with one another by a set of interactions that collectively are richer than its constituents and give rise to emergent properties. This complexity will be analyzed using the conceptual and practical framework of Network Science.

Bringing together more than 40 Université Laval professors from 3 faculties and 12 departments working with 15 collaborators from outside UL, this thematic project will explore northern systems at every scale, from the microscopic (microbiotes and biological systems), to the mesoscopic (preservation of biodiversity and sentinel species), and the macroscopic (ecosystem services, water management and quality, degradation of permafrost, infrastructure), combined with the development of powerful digital models, as well as a new generation of optical sensors with multiple networking capabilities.

Thematic project 1 research

THEMATIC PROJECT 2

LIGHT AS A DRIVER, ENVIRONMENT, AND INFORMATION CARRIER IN NATURAL ENVIRONMENTS AND HUMAN HEALTH

The exploitation of the remarkable potential of light by humans has led to profound transformations of our societies in multiple areas, including: health and safety, renewable and green energy, networking and communications, and the exploration of the multiple environments of our planet. In the North, major seasonal variations in photoperiod, vegetation, snow cover and ice cover lead to significant variability in the availability and quality of light affecting ecosystems and societies.

This thematic project brings together more than 60 Université Laval professors from 7 faculties and 13 departments, working with their 60+ external collaborators. Using new optical sensors and technologies deployed in a northern context, their main objectives are to: investigate the propagation of light through space and matter; study the influence of light on physiology and biorhythms; detect climatically active compounds; and generate sustainable energy.

Thematic project 2 research

2.1 Optimizing biophilia in extreme climates through architecture

2.2 Innovating optical systems to track winter life in the cryosphere

2.3 The use of diatom microalgae for improving the treatment of the light-driven dysfunctions of the biological clock in Arctic human populations

2.4 A better understanding of light-matter interaction: bringing the gap between micro and macro scales, and developing new devices and approaches for the North

2.5 Printed solar cells for small remote instruments

2.6 BOND: Beacons Of Northern Dynamics – Developing light based sensing technologies to monitor climate active gases in a mutating Arctic

2.7 Observing Arctic Substrates: Unveiling ice, water column, and benthic physical and biological properties using laser remote sensing from autonomous underwater vehicles and unmanned vehicles

2.8 Development, implementation and use of miniature portable technologies for the prevention, assessment and treatment of chronic diseases in the Northern areas

THEMATIC PROJECT 3

MICROBIOMES: SENTINELS OF THE NORTHERN ENVIRONMENT AND HUMAN HEALTH

Microbiomes are predominant in the atmosphere, hydrosphere, cryosphere, soils, fauna and humans. The main objective of this thematic project is to determine the roles of microbiomes in the northern human-environment ecosystem by focusing on ecosystems (land, freshwater, seawater), food quality (marine and terrestrial products) and human health (cardiometabolic, respiratory and mental). This broad transdisciplinary collaboration between the fields of physics, chemistry, biology, medicine and engineering will design, develop and deploy new compact instruments for microbiological monitoring in the environment, animal models and humans.

This effort brings together more than 100 Université Laval professors from 6 faculties and 18 departments working with 25 international, northern and industrial partners.

Thematic project 3 research

1.1 NETWORK ANALYSIS OF UMBRELLA AND INDICATOR SPECIES: ASSESSING THE INTEGRITY OF NORTHERN ECOSYSTEMS

Principal investigator

Daniel Fortin

Co-investigators

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Collaborators outside U. Laval

Marcel Darveau (Canard Illimités), Mark Hebblewhite (Montana, É.-U.), Christian Hébert (Ressources naturelles Canada)

Project summary

Biodiversity is central to ecosystem functioning and ecosystem services. Umbrella species can be used to simplify biodiversity conservation, as their protection results in the simultaneous protection of multiple co-occurring species over large areas. The forest-dwelling caribou is an umbrella species for boreal biodiversity that is also protected by law in Canada. Caribou conservation is already impacting the industrial development in northern ecosystems, and the situation may intensify as new areas become available for industrial exploitation following climate change. An effective contribution of caribou management to biodiversity preservation requires the ability to predict species diversity in changing environments and over large areas. Rapid climate changes in northern ecosystems will alter local conditions such that a given location can become more suitable to a different assemblage of species in a near future.

Our project aims at answering pressing management issues through a better understanding of the complexity, both structural and functional, of northern environments under climate change. By combining observations along latitudinal gradients and a suite of innovative numerical and complex network analysis methods, we will reveal the mechanisms underpinning the transition between ecosystems along the varying environmental conditions. We will develop tools to assess the integrity of northern ecosystems, and to anticipate, monitor, and eventually preserve biodiversity, the umbrella species, and their associated ecosystem services (e.g., timber supply, aesthetics, and cultural values) despite global changes. Our research outcomes can be used to identify suitable targets for ecosystem restoration and for the needs of local communities regarding sustained supply of ecosystem services (e.g., timber harvest, pollination), given ongoing environmental changes and anthropic pressure.

Access the project’s webpage

1.2 THE RESILIENCE OF COMPLEX NETWORKS: IDENTIFYING CRITICAL INDICATORS FOR EFFICIENT TARGETED INTERVENTIONS

Principal Investigators

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Co-Investigators

Antoine Allard, Daniel Côté, Paul De Koninck, Patrick Desrosiers, Nicolas Doyon

Collaborators

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Collaborators outside U. Laval

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Project summary

The ability of a system to adjust its activity to retain its basic functionality under errors, failures and environmental changes, its resilience, is a defining property of many complex systems. However, and despite widespread consequences on human health, economy and the environment, events leading to loss of resilience, from cascading failures in technological systems to mass extinctions in ecological networks, are still rarely predictable and more than often irreversible.

The North, with its diverse interconnected networks, is confronted with mounting challenges from rapid climatic, social and economic changes. We would do well to establish a comprehensive framework to deal with this vulnerable ecosystem. The network science (NS) approach offers such a theoretical and practical framework to address complex systems over microscopic (e.g. neural networks), mesoscopic (e.g. animal biodiversity), and macroscopic (e.g. human population/health and climate changes) scales.

At the very least, it offers a common universal language and unifying concepts to apprehend the dynamical, nonlinear, adaptive and hierarchical (complex) systems that we will face in the North. The relationship structure-function will be a leitmotiv of our study. To confront our general methodology with experimental reality, we will combine NS with Systems Biology at the microscopic level to focus our attention on the larval Zebrafish. It is an ideal animal model (the fruit fly of neuroscience) for its small size, transparency, rapid development, and most importantly, its amenability to optogenetics. This will allow the neurophotonics members of our team to image the activity of Zebrafish brain circuits when progressively or suddenly submitted to external (temperature and light) and internal (optical stimulation of neuronal populations) perturbations. By combining recent methods from network analysis and simulations of dynamical systems, we will then compare the theoretical/numerical results with the Zebrafish experiments, as well as with other observable networks of the North.

Access the project’s webpage

1.3 CHARACTERIZATION AND MODELLING OF THE KEY INTERRELATIONSHIPS OF NORTHERN WATER SYSTEMS UNDER CLIMATIC, GEOSYSTEMIC AND SOCIETAL PRESSURES

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Collaborators
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Collaborators outside U. Laval
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Project summary
Our multidisciplinary team of researchers from the natural sciences, applied mathematics, engineering, and health sciences proposes to document and model the key interrelationships of northern water systems, under climatic, geosystemic and societal pressures. Northern water systems include the terrestrial hydrosphere (surface and ground water) and cryosphere (ice, snow, permafrost). Three main issues will be investigated: the lack of hydrometeorological data and models in the north, the need to predict the impact of thawing permafrost on water resources, infrastructure, and the environment, and the long-term need for safe drinking water for northern communities. We will use advanced analytical techniques for data collection, including optics-photonics devices, and develop the most advanced numerical models for hydrometeorological simulations and permafrost dynamics. A major component of the project will be field investigations at several northern sites, including Umiujaq and Salluit in Nunavik, QC.

The expected outcome includes: collection of unique data on water and energy budgets that will provide essential input to improve operational land surface models used for weather forecasting and climate modelling, unique large-scale data on permafrost degradation in sensitive areas leading to the development of the next generation of models to simulate the dynamics of permafrost degradation, and the development of low cost light-based methods to monitor in situ drinking water quality, leading to water treatment methods and monitoring strategies adapted to the north. We will closely collaborate with partners from northern organizations, industry, and government to ensure knowledge mobilization and transfer, based on our team's extensive track-record of conducting collaborative research with non-academic partners. This project represents a unique opportunity to establish Sentinel North among international research leaders in northern water systems.

Access the project’s webpage

1.4 PHOTONIC ULTIMATE SENSING (PULSE) AND MONITORING OF PERMAFROST ENVIRONMENTS

Principal Investigators
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Co-Investigators
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Collaborators
Jean-Michel Lemieux, Warwick Vincent

Project summary

The north is evolving rapidly under the pressure of social and economic development in a context of accelerating climate changes. To improve our understanding of these dynamics, we propose novel photonic platforms to monitor parameters critical to the sustainable development of the north, namely permafrost degradation below ground and at surface, greenhouse gas emissions, and water properties. This research addresses the following needs:

Sensing deep permafrost: Distributed fibre optic sensing systems deployed in deep borehole will provide multi-parameter sensing, including temperature, strain, groundwater pressure and flow rate, to ensure the sustainable and safe exploitation of mineral deposits below the permafrost base.

Greenhouse gas emissions: Silicon photonic sensors will monitor gas build-up from natural and industrial sources (e.g. CH4, CO and CO2) in underground mineral exploitation and degrading permafrost environment.

Resolving ground surface dynamics: Buried fiber optic sensors and adaptive cameras for 3D imaging will be co-installed a test site to monitor the impacts of permafrost degradation such as thaw subsidence of the ground surface. High-resolution ground movement monitoring will provide key inputs to models describing the ecosystem dynamics and predicting the stability of man-made infrastructures.

Water quality monitoring with self-powered sensors: Autonomous energy source based on benthic microbial fuel cell will be developed to power up microfluidic and silicon photonic sensors. These sensors will find application in thermokarst ponds and wells.

Outcomes of this sub-project will be robust, low power consumption, and versatile platforms acting as unique sentinels of northern environments under stress: fiber-based sensors, silicon photonic integrated sensors, self-powered microfluidic sensors, and adaptive 3D cameras that will provide essential information to cold-regions engineers (ex. mining, geotechnical, and civil), and scientists (hydrogeologists, biologists and chemists) for the sustainable development of the north.

Access the project’s webpage

1.5 PITUTSIMANIQ, NETWORKED SENSOR SENTINELS FOR REAL-TIME SURVEILLANCE OF INFRASTRUCTURES AND ECOSYSTEMS

Principal Investigators
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Collaborators
David Conciator, Ariane Locat

Collaborators outside U. Laval
Anderson S. L. Gomes

Project summary
Pitutsimaniq, network in Inuktitut, captures the essence of this project that targets interconnectivity of infrastructure monitoring systems for immediate benefit to northern communities. Construction, expansion, and land-use planning are required for economic development of a fast-growing population in northern communities, yet they are troubled by climate change and destabilizing permafrost. Communication networks dedicated to monitoring ecosystems and infrastructures could provide tremendous capabilities: real-time observation of climate change impact, hazard detection, early warning of risks, assessment of performance of applied adaptive designs, and enabling fast decision making. Sentinels of change today are isolated silos – sensors and data-loggers patiently gathering precious readings for researchers and users who can access them only a few times a year.

Researchers, northern communities and infrastructure owners need real-time surveillance of the environment and infrastructure. Intelligent, interconnected networks of sensors, conveying the latest trends as well as impending cataclysms, can usher in a new era of innovation, an inflection point in the pace of human understanding of climate change, even as that change accelerates. We propose basic research into networks of low-cost sensors endowed with the capacity to read and store data, transmit this information under harsh climatic conditions, and all with minimal energy consumption. Networked sensors covering the whole length of linear transportation infrastructure and the spatial extent of communities will give warning of incipient failures in covered areas by detecting nascent localized heat sources in the terrain. Longer term, innovative fiber-based sensors will be developed for ground temperature, infrastructure behavior, and ecosystem dynamics. These intelligent networking elements will be transplanted into the panoply of innovative Sentinel North sensors developed by other teams, thus providing deeper insight and understanding of the impact on the environment and man-made infrastructure.

Access the project’s webpage

2.1 OPTIMIZING BIOPHILIA IN EXTREME CLIMATES THROUGH ARCHITECTURE

Principal Investigators
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Co-Investigators
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Collaborators
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Collaborators outside U. Laval
Ellen Avard, Mylène Riva, Claude Vallée

Project summary

Biophilia defines the innate attractiveness of humans towards nature, daylighting being its primary vector. This research project proposes to optimize biophilia by creating a living environment adapted to the limited availability of natural light in extreme climates. As a genuine extension of the body, architecture stands between nature and humans and expresses the tangible meeting point of climate, biology and technology. Architecture integrated to its environment and cultural context expands the space of the biological and social balance point and secures a favourable environment for productivity, health and well-being while minimizing negative impacts on the environment. In the context of limited light and resources, occupants or temporary workers of the North depend on a highly technological building culture to adapt to often hostile environments. However, inhabitants of the North –especially Inuit communities- have developed a rich architectural culture intimately adapted to the biosphere, which has gradually subsided in contact with Southern lifestyles and access to resources.

The project proposes to meet the biophilic needs of both cultures through the following research activities:

- measurement of the availability of natural light and its impact on human well-being, energy demand of buildings, and potential for vegetalization
- development of optical technologies (LED, Smart Windows, Optical Fiber) to optimize the well-being of users, minimize the energy intensity of buildings and promote ecological restauration
- integration of optical technologies to architectural and building components to auxiliary spaces or 'biophilic prostheses' to existing buildings (communal and/or residential spaces)
- and validation of the effectiveness, applicability and cultural acceptability of the solutions by architectural design solutions

Access the project’s webpage

2.2 INNOVATIVE OPTICAL SYSTEMS TO TRACK WINTER LIFE IN THE CRYOSPHERE

Principal Investigators
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Co-Investigators
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Collaborator
Benoit Gosselin

Collaborators outside U. Laval
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Project summary
Winter has been traditionally considered a «dormant» period for life in the Arctic but events occurring in winter can still play a vital role for living organisms. Changes in the condition of the snow, a universal defining feature of winter at high latitudes, and its effects on transmission of light have cascading effects on organisms living in the North and affect ecosystem services. However, our knowledge of those processes is minimal due to the difficulty of studying this environment in winter and represents an emerging great frontier of Arctic science. Our project will use recent developments in optical systems to study arctic ecosystems in winter. Our overall objective is to develop and apply new optic-based technologies under the harsh arctic conditions to improve our understanding of snow properties and their impacts on living organisms. We propose to:

1) develop novel optical technologies to measure in situ key snow properties,
2) develop new optical tools to track the activity of small animals living under the snow
3) use large moving animals equipped with optical devices to monitor snow and environmental conditions and
4) develop optical systems to measure light transmission and biological processes in the water column under the ice.

Our project will lead to scientific and technological breakthroughs in our understanding of arctic ecosystems during winter. For this project, we will develop instruments using innovative technologies (e.g. resistance to cold, ability to operate under low light intensity, low energy consumption) that are bound to find many applications beyond this project. A close collaboration among researchers with unique expertise in disciplines as diverse as biology, chemistry, photonic and electrical engineering is essential to achieve our goals. This project will provide a unique training environment for graduate students by combining diverse expertise in the laboratory and in the field in the Arctic.

Access the project’s webpage

2.3 THE USE OF DIATOM MICROALGAE FOR IMPROVING THE TREATMENT OF THE LIGHT-DRIVEN DYSFUNCTIONS OF THE BIOLOGICAL CLOCK IN ARCTIC HUMAN POPULATIONS

Principal Investigator
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Co-Investigator
Marc Hébert

Collaborator
Marcel Babin

Collaborators outside U. Laval
Angela Falciatore

Project summary
In the Arctic, the biological activity, from the diatom microalgae to humans, is strongly constrained by light which shows extreme seasonal and daily variations in irradiance and in spectrum. The strong blue vs. red light spectrum experienced by diatoms in sea-ice and water is opposite to the human eye sensitivity (high for red and low for blue light) arguing for a relevant blue-light responsive biological model. Diatoms and humans have evolved circadian clocks regulated by sophisticated molecular devices for synchronizing their physiology with their light environment. The regulation of their biological rhythms shows striking common features (‘convergent evolution') like blue- and red-light photoreceptors, and clock component with animal features in diatoms. The deleterious effects of the light climate on human mental health (seasonal affective disorder, etc.), especially in the North, are well-known. Artificial blue:red lighting (i.e. luminotherapy) is an innovative approach to ‘trick' the biological clock and boosts the circadian rhythm. Testing new light regimens on statistically relevant human populations is difficult while this is more feasible in Arctic diatoms.

The aim of this project is to use Arctic diatoms to study the effect of photoperiod and light spectrum on the circadian rhythmicity of physiology in order to propose new blue:red light regimens with positive effect on the biological clock. It will subsequently facilitate their application in Northern populations (and beyond, i.e. night workers, miners, etc.) with increased probability of mental health and behavior dysfunctions. It will potentially generate new patent(s) for non-invasive medical light treatment (LEDs, glasses with filters). In parallel, the project will 1) deepen our knowledge of the fundamental regulatory processes behind the light-driven ecophysiology of diatoms, the sentinels of climate changes in the Arctic, 2) open on bioprospection of added-value molecules beneficial to human health, i.e. carotenoid pigments and polyunsaturated lipids found in Arctic diatoms.

Access the project’s webpage

2.4 A BETTER UNDERSTANDING OF LIGHT-MATTER INTERACTION: BRIDGING THE GAP BETWEEN MICRO AND MACRO SCALES, AND DEVELOPING NEW DEVICES AND APPROACHES FOR THE NORTH

Principal investigator
Pierre Marquet

Co-Investigators
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Collaborator
Marcel Babin

Collaborators outside U. Laval
Pierre Francus

Project summary

The accurate knowledge of light distribution in diffusive media is invaluable to understand how light shapes our environment (e.g., photosynthesis in the oceans) and helps us decipher it (e.g., diagnosis with light). Yet, despite years of advances in the field, models of light propagation in diffusive media often rely on approximations that neglect details of the microscopic structure of matter. Therefore, our models aiming at providing a comprehensive understanding of important phenomena resulting from these light-matter interactions in diffuse media fail in different situations. For example, light distribution under the ice cap would enable a better understanding of marine ecosystems. In addition, with the design of ever smaller optical probes operating in non-diffusive regime, the shortcomings of the current light transport models become apparent and amount to a lost opportunity: better models would provide more accurate tissue characterization. Considering that these modeling shortcomings result noticeably from a lack a data concerning the structural organisation of these diffusive media, we propose a strategy aiming at

1) collecting structural data with relevance to optics from both sea ice as well as biological tissues

2) feeding different radiative transfer models with these relevant structural parameters and

3) developing cutting-edge computational modeling strategies that take these microscopic parameters into account.

These new radiative transfer models will pave the way to gain substantial information about the impact of climate change on marine ecosystems, and to develop efficient miniature instruments for rapid diagnoses concerning in particular dermatological issues and circadian rhythm disorders for Northern populations.

[Access the project’s webpage]

2.5 PRINTED SOLAR CELLS FOR SMALL REMOTE INSTRUMENTS

Principal investigator
Mario Leclerc

Co-Investigators
Paul Jonhson, Jean-François Morin, Simon Thibault

Collaborator outside U. Laval
Ian Hill

Project summary
The project proposed herein aimed at developing a printed energy device that could be installed on small remote devices requiring low electrical power such as optical sensors, imaging tools and communication devices. The purpose of this technology will be to supply energy on-demand without the use of heavy battery that required frequent recharge and on-site maintenance. To achieve this goal, a team of two materials scientists (M Leclerc and JF Morin, Department of Chemistry, ULaval), one computational chemist (P Johnson, Department of Chemistry, ULaval), one physicist (S Thibault, Departement of Physics, Physics engineering and Optics, ULaval), one external collaborator (Ian Hill, Dalhousie) and one industrial partner (ICI - College Ahuntsic) will team up to develop and integrate all the parts of the device. Leclerc and Morin will develop light-harvesting semiconducting materials, based on the design and calculations made by Johnson, and proceed to their integration into solar cells. Thibault will develop concentrators to increase sunlight harvesting efficiency.

Hill will be responsible for the prototyping of the solar cells while ICI will print all the components of the device onto flexible substrate, including the batteries to store the energy produced by the solar cells. The printing technology allows fabrication of very thin, lightweight and flexible devices that could fit any electrical devices geometry while being unaffected by mechanical deformations. These are all significant advantages over the classical silicon-based solar cells technology whose heavy weight, brittleness and poor mechanical properties make such devices inappropriate for applications in harsh environmental conditions like those found in the Arctic.

Access the project’s webpage

2.6 BEACONS OF NORTHERN DYNAMICS (BOND) – DEVELOPING LIGHT-BASED SENSING TECHNOLOGIES TO MONITOR CLIMATE ACTIVE GASES IN A MUTATING ARCTIC

Principal Investigators
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Collaborators
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Collaborators outside U. Laval
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Project summary
The impetus underpinning the BOND project lies in the urgency to monitor the fast-pace changes in the Arctic environment. Ongoing climate shifts are provoking profound modifications in the atmosphere as well as in physical landmarks and most prominently within the cryosphere comprised of sea ice, lake and river ice, glaciers, ice caps, ice sheets and permafrost. Important changes in the rate and timing of freshwater discharge are also expected. These wavering northern environments are hosts to diverse and complex ecosystems, within which biogeochemical cycles of major elements such as carbon, nitrogen, oxygen, and sulfur drive the overturning and exchanges of climate active (CA) gases such as carbon dioxide, methane, nitrous oxide, and dimethylsulfide. Gaining insight into the abiotic- and biotic-driven kinetics of these CA gases requires high-frequency measurements of fluxes and reservoirs: a challenging endeavour in these remote areas. Various optical approaches will be explored in order to meet the challenges related to real-time and remote detection of CA gases in the atmospheric boundary layer and soils as well as aquatic environments themselves.

To address the challenges of atmospheric and aquatic gas detection, BOND will build upon and further achieve technological advancements on photonic devices. Atmospheric gas detection will rely on specially designed mid-IR coherent sources whereas underwater probing challenges will be tackled through the development of optode sensors based on the synthesis of new chelating fluorescent complexes. In-house development of these monitoring systems will first be achieved, followed by their in-situ deployment in the Arctic environment. Parallel laboratory experiments implementing novel bio-reactors coupled to high resolution mass spectrometry (MIMS) analysis will allow fine-scale resolution of the processes driving CA gas kinetics. Together, these pioneering approaches will materialize BOND's main objective: the implementation of leading-edge optical monitoring devices acting as the early warning Beacons Of Northern Dynamics.

Access the project’s webpage

2.7 OBSERVING ARCTIC SUBSTRATES: UNVEILING ICE, WATER COLUMN, AND BENTHIC PHYSICAL AND BIOLOGICAL PROPERTIES USING LASER REMOTE SENSING FROM AUTONOMOUS UNDERWATER VEHICLES AND UNMANNED AERIAL VEHICLES

Principal investigator
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Co-Investigator
Michel Piché

Collaborators
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Collaborators outside U. Laval
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Project summary
The physical and biological properties of Arctic ice and coastal benthos remain poorly understood due to the difficulty of accessing these substrates in ice-covered waters. A Light Detection And Ranging (LiDAR) system deployed on an autonomous underwater vehicle (AUV) can interrogate these surfaces in three dimensions for physical and biological properties simultaneously. Using the absorption, inelastic scattering (fluorescence), and elastic scattering properties of photosynthetic micro- and macro-algae excited by lasers, we propose to quantify the physical features of the substrate (ice, benthic assemblages, geology) as well as biomass from an AUV.

We propose a modular, incremental instrument development approach, starting with a single-wavelength, continuous wave system already developed for ice detection. Through radiative transfer modeling and source and/or detector wavelength changes, fluorescence and differential absorption capabilities will be developed. Adding time-response pulsed laser capability (true LiDAR) will allow depth resolution of ice draft, bottom ice algae and benthic algae and water column microalgae. Finally, scanning or structured illumination techniques can be added to create three dimensional images of the substrate, significantly increasing the sampled area.

Access the project's webpage

2.8 DEVELOPMENT, IMPLEMENTATION AND USE OF MINIATURE PORTABLE TECHNOLOGIES FOR THE PREVENTION, ASSESSMENT AND TREATMENT OF CHRONIC DISEASES IN NORTHERN AREAS

Principal investigator
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Co-Investigators
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Collaborators
Charles Batcho, Alexandre Campeau-Lecours, Bradford McFadyen, Catherine Mercier, Philippe Archambault

Collaborator outside U. Laval
André Plamondon

Project summary
Current transformation of the North caused by global warming is leading to a rapid development and diversification of human activity and work. With these rapid changes occurring in challenging and less known environments, safety and health of northern populations (local and workers) represent areas of concern. The purpose of this project is to develop, deploy and validate new portable technologies (fiber-optic-based movement sensors and low-power miniature physiological sensors) to remotely monitor in real-time motor skills, mobility, and vital metabolic variables. These technologies will be used to evaluate and guide treatment for individuals with chronic diseases and / or physical disability (work-related or not). In addition, the data collected will later be used to develop predictive models to prevent the development of such diseases/disabilities.

Due to the novelty of the technologies and the wealth/complexity of the collected data, this project will lead to the creation of new intersectorial collaborations between Université Laval's researchers, the members of 3 provincial research networks (rehabilitation, pain and technology), and a private partner in remote collection/processing of health data. Experts in human rehabilitation, work risk assessment, software and hardware engineering, data processing (predictive modeling / epidemiology), psychology and motor control/neuroscience, will tackle together the challenge of quantifying human behavior in a real-world challenging environment and to relate it to health indicators.

Access the project's webpage

3.1 SENTINEL MICROBIOMES FOR ARCTIC ECOSYSTEM HEALTH

Principal Investigators

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Collaborators

Dermot Antoniades, Jacques Corbeil, Patrick Desrosiers, André Marette, Pierre Marquet, Sylvain Moineau, Jean-Sébastien Moore, Mohammed Taghavi

Collaborators outside U. Laval

Abdel El Abed (France), Jérôme Comte (INRS), Anne Jungblut (Royaume-Uni), Weidong Kong (Chine), Isabelle Laurion (INRS), Rachael Morgan-Kiss (Floride), Milla Rautio (UQAC), Yukiko Tanabe (Japon)

Project summary

The Arctic is warming at rates more than twice the global average, and much larger changes are projected for high northern latitudes by the end of this century. This proposal addresses the question: what sentinel microbiome properties of northern marine and freshwater environments can be used to improve surveillance of Arctic ecosystem health in the face of these increasing perturbations? We will harness a broad range of expertise at Université Laval, from molecular biology, chemistry and physics to aquatic ecosystem science, and will extend our scope of activities by collaborating with research centres operating in the Canadian North and with industry. Our first aim will be to identify the composition, complex system properties and resilience of two classes of Arctic microbiomes: planktonic and biofilms. Our approach will harness the power of metagenomics to address knowledge gaps in how to define sentinel microbiomes for the Arctic, and to identify what microbiome properties can be used to determine changes in the health of Arctic ecosystems. We will target:

i) environmental microbiomes in a comprehensive set of northern marine and freshwater ecosystems including Baffin Bay, Hudson Bay, lakes and fjords in northern Nunavut and permafrost wetlands in Nunavut;
ii) host-associated microbiomes of the iconic fish species of the North, Arctic char, with emphasis on the impact of both native and invasive pathogenic species on the productivity and sustainability of this major resource.

Our second important aim will be to develop two types of novel optical instruments for the central goal of Arctic microbiome surveillance:

i) a multimodal opto-fluidics system that can detect and sort specific classes of planktonic cells; and
ii) a portable hyperspectral Raman imaging system to quantify microbial biomass via cellular lipids, and to obtain lipid signatures of host-associated and free-living biofilms.

Access the project’s webpage

3.2 COMPREHENSIVE ENVIRONMENTAL MONITORING AND VALORISATION: FROM MOLECULES TO MICROORGANISMS

Principal investigator

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Co-Investigators

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Collaborators

Patrick Lague, Warwick Vincent

Project summary

The aim of this research program is to understand how the disruption of ecosystems affects microorganisms in Arctic soils. To achieve our goals, we will use the EcoChip, a microbial in situ culture system for measuring the growth of microorganisms in their natural environment that also enables acquiring and transmitting real-time environmental metadata. The sites under consideration for the deployment of EcoChip span 30 degrees of latitude in the Northern regions and part of the SILA environmental network. We aim to identify sentinel bacteria and investigate how spatiotemporal features affect the microbial consortia. We will design analytical approaches based on integrative genomics, bioinformatics, geolocation and machine learning to quantify the health of Northern ecosystems by measuring in real time these key microbial markers.

Our program will enable making predictions of the impact of large-scale environmental changes due to climate change or human intervention on the microorganisms and the functioning of terrestrial ecosystems. In situ analysis of microorganisms with EcoChip will also allow to develop high performance metabolomic models to assess the Nordic molecular diversity and to discover new compounds with potential medical applications including the treatment of tuberculosis. We will therefore use our new high throughput metabolomic mass spectrometry approaches coupled to machine learning in order to accelerate the process of identifying molecules having potential medicinal properties. We will be in a position to exploit the potential of bioproducts for their clinical or industrial uses. With these tools, we will be able to evaluate the impact of environmental changes in the North and effectively add value to the microorganisms found in these environments. At the end of our initiative, we will greatly improve our understanding of the changes occurring in the Northern environments and their impact on human health.

Access the project’s webpage

3.3 BRIGHT (BRIDGING GLOBAL CHANGE, INUIT HEALTH AND THE TRANSFORMING ARCTIC OCEAN)

Principal Investigators

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Project summary

Local marine foods (LMF) are central to Inuit culture and subsistence in the Arctic. Conversely, the Arctic Ocean is changing and Inuit see signs that LMF are different and becoming less accessible. Inuit make food choices according to their preferences but also the accessibility, abundance, visual appearance and quality of different LMF. These four characteristics of LMF are strongly tied to the light environment via the photosynthetic production of microalgal biomass, which is the main entry point for energy, numerous vital or health-enhancing molecules, and contaminants into the food web. Yet we do not know how the quantity and proportion of these substances in algae, zooplankton and LMF respond to climate-driven changes in sea ice, light availability and the physicochemical properties of Arctic seawater, how this response modifies the food choices of Inuit and impacts their health and wellbeing. BriGHT will 1) assess the synergistic effects of light, warming, acidification and nutrient availability on the accumulation of contaminants and the production of health-enhancing molecules in microalgae, 2) model the transfer of these substances from algae to the upper food web, 3) quantify these substances in LMF and the blood of Inuit with respect to their food consumption profiles, the visual appearance of LMF, and indicators of food security, well-being and physical and mental health, and 4) implement novel genomic approaches to monitor spatial and temporal changes in the presence and abundance of LMF.

The work will integrate oceanographic sampling, optics, ecosystem modeling and a metagenomic study of Arctic Char foraging in Nunavik, building a synergy with the 2017 Qanuilirpitaa Health Survey. These results will allow to model plausible climate-driven trajectories in LMF characteristics and their likely impact on Inuit health and wellbeing, assisting with the formulation of locally-adapted mitigation adaptation strategies aimed at promoting Inuit local food systems and security in Nunavik.

Access the project’s webpage

3.4 ENABLING TOOLS FOR THE MONITORING OF FOOD QUALITY IN THE NORTHERN ENVIRONMENT

Co-leaders

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Co-Investigators

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Collaborators outside U. Laval

Ellen Avard, Michael Kwan

Project Summary

The health benefits of country foods from the land, the rivers and the sea as well as the harmful effects of contaminants that may be found in some of them are well documented in Nunavik. However, important aspects of country foods necessitate further study at community level. For example, contaminant levels in lake trout may change from one fish to another depending on location, age and size. A transdisciplinary team gathering U. Laval experts in analytical chemistry, photonic materials, engineering and instrument design, microfluidics, toxicology, psychology and public health, in collaboration with the Nunavik Research Centre, will develop a portable analysis platform for in-the-field testing of various metal contaminants and essential nutrients in country foods. In a second step, partnering with the Nunavik Regional Board of Health and Social Services, we will develop a knowledge user tool to support decision making for local community members and health professionals about the quality of foods in their community. The analysed chemical species will be mercury and lead.

The platform will be designed to automatically handle all fluid mixing, optical readout and data logging, making it a user-friendly apparatus, easily operated by untrained personnel. This will be achieved by integrating species-selective capture and chemosensitive photonic materials in microfluidic devices for which the design will have been optimized. The platform and decision making tools will be field-tested and improved upon feedbacks from local community organisations. Fostering local capacities with respect to food analysis and improving access to local information about food quality will enhance Inuit autonomy with respect to food choices and the benefits and safety of their foods and, in the longer term, help to improve food security, health and well-being in Nunavik.

Access the project’s webpage

3.5 IMPACT OF ENVIRONMENTAL CONDITIONS ON AIRWAY MICROBIOTA AND RESPIRATORY HEALTH IN THE NORTH

Principal Investigators

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Co-Investigators

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Collaborators

Yves Lacasse, Philippe Leprohon, Benoit Levesque, Frédéric Raymond

Project summary

The aboriginal populations of the North are facing an unprecedented epidemic of respiratory diseases, which is intimately linked to rapidly occurring changes in lifestyle and environmental conditions that have been taken place during the past 20 years. High smoking rates and overcrowded and poorly ventilated homes create a fertile ground for the development of respiratory diseases. Less appreciated is the fact that chronic respiratory diseases often co-exist with cardiometabolic disorders, creating even more complex health problems.

The rationale of this proposal is that understanding how the Nordic environment influences the development of chronic respiratory diseases is a crucial step in improving aboriginal health. We hypothesize that modifications in the airway microbiota due to these extreme living conditions provide a plausible link between poor environmental conditions and respiratory diseases. Our objective is to generate crucial information about the impact and development of respiratory diseases in the North that will lead to effective preventive and therapeutic strategies. We will leverage on the 2017 Nunavik Inuit Health Survey (NIHS 2017) that will investigate respiratory health, lifestyle habits, and lung function by

i) evaluating the upper airway microbiota of 1000 Inuits aged 18- 30 years and of ≈ 800 participants from the 2004 health survey from the 14 Nunavik communities, and

ii) documenting, in a subset of subjects (n = 84) from these two cohorts, the air microbiological environment of their home.

Considering that cardiometabolic health and gut microbiota will also be evaluated, we propose to study the interplay between respiratory and cardiometabolic diseases in relationship with the airway and gut microbiota. The clinical investigation will be supplemented by in vivo experimentations allowing to address the research questions in a mechanistic fashion. Knowledge transfer activities and technological development are planned, notably by validating a new method to assess the airway microbiota in a pragmatic way.

[Access the project’s webpage]

3.6 THE GUT MICROBIOME: SENTINEL OF THE NORTHERN ENVIRONMENT AND INUIT MENTAL HEALTH

Principal Investigators

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Collaborators

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Collaborators outside U. Laval

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Project summary

The proposed project is based on findings from previous Nunavik Inuit health survey conducted in 1992 and 2004, which have documented cumulative exposure to adversity among communities (environmental contaminants, food insecurity, victimization, substance use), and high prevalence of psychological distress. Focusing on the 16-30 years old participants from the next population based Nunavik Inuit health survey to be conducted in 2017, this project aims to examine the role of gut microbiome in the association between adversity and mental health. Using the study's global evaluation of health to explore gut microbiome profiles, their association with depressive state will be evaluated using case-control design. The same microbiome profiles will then be link to diverse source and level of adversity lived by young Inuit from Nunavik, but also to several biological markers. As a possible explanation to expected associations, neuronal resiliency specific to Inuit from Nunavik will be explored. As an addition to current efforts taking place in the communities, this project includes in its budget, in addition to a strong transdisciplinary academic plan for students:

1) the collection and analysis of fecal samples used to identify microbiome profiles,
2) the analysis of metabolome and inflammatory biomarkers,
3) the use of electroretinography as an novel indicator of mental health problems and
4) neuronal culture from induced pluripotent stem cells, and
5) the latest and most performing analytical processes.

A more comprehensive understanding of mental health problems by integrating involved internal and external environmental aspects of human total exposure is anticipated. Novel markers of adversity, but eventually of psychological distress are projected. Researchers and partners to the project aim to carry both innovation and factors of resilience at the population level.

Access the project's webpage

3.7 OPTOGENETICS INVESTIGATION OF MICROBIOTA INFLUENCE ON BRAIN DEVELOPMENT AND EPIGENETICS

Principal Investigators

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Co-Investigators

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Collaborators outside U. Laval

Robert Campbell, Patrice Couture

Project summary

The intestinal microorganisms hosted by humans and other vertebrates play a central role in maintaining their hosts in healthy conditions. However, when the host encounters a physiological stress, the microbiota ecosystem equilibrium is broken, allowing opportunistic microbial strains to induce negative effects on the host, including infections and physiological disturbances. During host development, a stressed microbiota might induce significant consequences on its brain development and neural functions, affecting mental health. The Northern ecosystem is undergoing unprecedented assaults from human activities, leading to dramatic environmental changes that are modifying host-microbiota interactions. The relationships between these complex systems are poorly understood. To learn more about host-microbiota interactions and their impact on mental health, we must develop models and tools with which we can accurately control the variables, relevant to the environment, in a laboratory setting.

Our objective is to develop a fish experimental model in which we can control factors that modulate host-microbiota functional interactions and measure the impact on microbiota evolution, on brain function, and on host gene expression. Our specific aims are to

i) develop molecular tools to study and control microbiota metabolism and growth with optogenetics;
ii) develop multispectral optical imaging of the co-evolution of bacterial strains;
iii) investigate the impact of nutrition, xenobiotics, phages and bacterial strains on the gut microbiota, on neuronal development and brain circuit function and on epigenetics.

The proposed project will involve a transdisciplinary approach combining physiology, optogenetics control and monitoring of gut microbiota, optogenetics monitoring of neural function, as well as genomics and transcriptomics analyses of horizontal gene transfer in bacterial strains, and epigenetics analyses on developing host. The project will lay the foundation of an experimental setting in which several variables critically important to Northern ecosystems will be investigated.

Access the project’s webpage

3.8 DECIPHERING HOST-MICROBIAL INTERACTIONS FOR CARDIOMETABOLIC AND MENTAL HEALTH DISORDERS WITH NOVEL MULTIMODAL LIGHT-BASED SENSING TOOLS

Principal Investigators

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Collaborators outside U. Laval

Patrice Cani (Belgique), Emile Levy (CHU Sainte-Justine)

Project summary

Obesity, cardiometabolic diseases (CMD) and mental health disorders (MHD) are major public health issues among indigenous populations in the Canadian North. It is hypothesized that exposure to various environmental factors, known as the “exposome”, that include changes from a traditional to a more western-type diet, is causing perturbations in the gut microbiome, which may provide a common pathogenic link for the increased prevalence of CMD and MHD in these populations. This new understanding is causing a revolution in the medical field, which is in urgent need of better predictive biomarkers (sentinels) to establish a rapid and efficient diagnostic for these prevalent diseases. We have assembled a new transdisciplinary team of experienced scientists at Université Laval that will transcend the usual academic boundaries and, working together with other prestigious academic institutions and industrial partners, develop and validate new “Sensor-in-Fiber” optical probes using latest advances in fiber optics and photonic materials. These revolutionary opto-microbiomic tools will be implanted in the gastro-intestinal tract of well-established mouse models of CMD and MHD for in situ and simultaneous detection of key microbiome-derived molecules with unsurpassed sensitivity and high spatial and temporal resolution. These novel monitoring tools will allow, for the first time, the sensitive and real-time analysis of the gut microbiota in vivo, leading to the identification of novel microbiome-derived biomarkers and biological targets for a better understanding of the relationship between the exposome and the developmental trajectory of CMD and MHD.

The main outcomes of this project are:

1) the unprecedented ability to monitor in situ and in realtime potentially novel microbiome-derived biomarkers of CMD and MHD diseases that are relevant to Northern communities, and

2) the discovery of new microbiome mechanisms underlying the health effects of wild berry polyphenols and fish ω3 fatty acids that are traditionally consumed in the North.

Access the project’s webpage