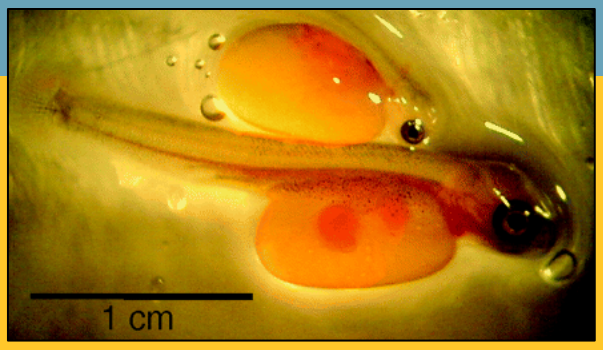

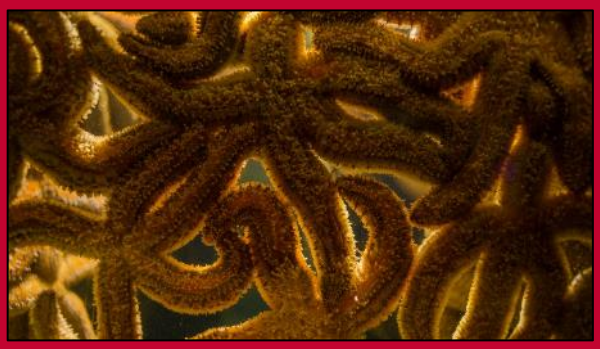

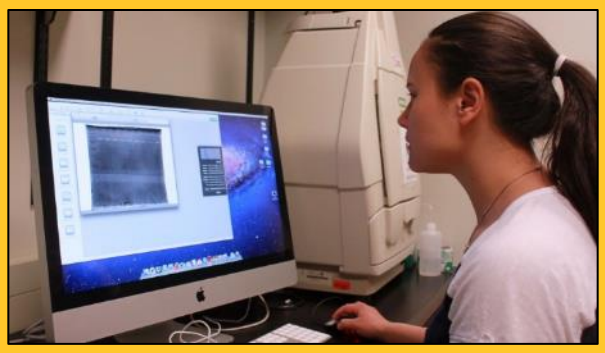

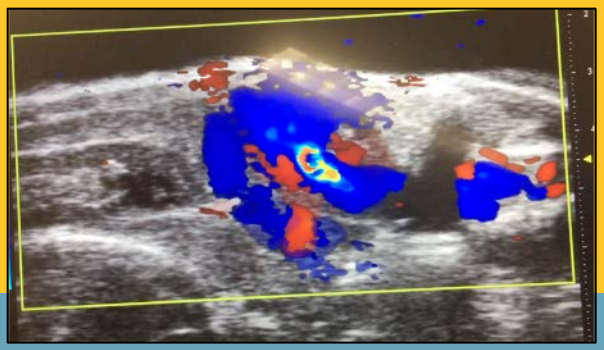

Hagen Aqualab

Advancing Aquatic Biology Research for Over 25 Years

January 2023

Produced by the Office of the Associate Dean of Research and Graduate Studies, College of Biological Science.

We thank Matt Cornish, Glen Van Der Kraak, and Todd Gillis for providing us with extremely valuable information for this report, as well as the many faculty members who shared additional information with us about their experience using Aqualab.

Cover photo credits: Matt Cornish, Colourbox, Hagen Aqualab, St. John Youth Division Guelph, Todd Gillis.

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COLLEGE of BIOLOGICAL SCIENCE

ASSOCIATE DEAN OF RESEARCH OFFICE

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Hagen Aqualab is a pioneering facility at the University of Guelph (U of G) that has been instrumental in advancing leading-edge research, teaching, and outreach in the freshwater and marine sciences for over 25 years. Designed and engineered to provide maximum flexibility for research space and drawing on chlorine-free, untreated well water (a crucial requirement for advanced research on aquatic species), the Hagen Aqualab enables research excellence while also conserving valuable natural resources through the use of state-of-the-art water recirculation technology. Since its establishment in 1997 with an initial investment of $6 million, the Hagen Aqualab has continued to enhance its infrastructure and expand its research and teaching operations through federal grants, institutional investments, donor and partner contributions, and user fees, bringing the total investment in the facility to date to $12 million. An additional $2 million for additional Aqualab infrastructure is currently under review as part of a larger (~$14 million) Canada Foundation for Innovation (CFI) proposal to support aquatic science.

The Aqualab supports research and teaching on a diverse range of aquatic animals including salmonid fish, zebrafish, yellow perch, goldfish, hagfish and tropical fish, as well as reptiles, amphibians, corals, sea urchins, freshwater mussels, and zooplankton. Research projects are similarly diverse and multidisciplinary, ranging from nutrient and trophic dynamics to embryology, conservation and restoration, environmental adaptation, stress and metabolism, evolution and speciation, physiology and anatomy, biophysics, biomimetics, biomechanics, neurobiology, immunology, toxicology and risk assessment, and cancer research, among others. The Aqualab's longstanding excellence in the natural sciences is complemented by its growing strength in the health sciences, due in large part to the increasing popularity of zebrafish as a valuable animal model to study cardiac disease, stress, cancer and neurological disorders, among other pathologies. The use of chlorine-free, untreated well water is paramount for mitigating animal stress in these molecular models, and therefore Aqualab researchers are uniquely

positioned to leverage their basic knowledge to cutting-edge translational health research.

The proximity of the Hagen Aqualab to the Science Complex has enabled faculty within the College of Biological Science (CBS), as well as across U of G, to strategically harness the strength of our combined research facilities to conduct innovative and integrative research. Research in the Aqualab supports multiple strategic initiatives at the University of Guelph, including One Health, Food from Thought, the Ontario Agri-Food Innovation Alliance, and the newly revisioned Biodiversity Institute for Conservation Synthesis. It is also central to longstanding research strengths at the University (animal and human health, biodiversity, environmental science, ecology, agriculture) that are consistently identified as core research themes in the institution's strategic research plans. The Hagen Aqualab remains the premier aquatic research facility in Canada and thus will continue to play a crucial role in helping the University's research community meet the most pressing challenges of the 21st century related to sustainability, global change, and human health. This reputation has resulted in unique opportunities for U of G, including collaborations with Ripley's Aquarium.

Currently, the Hagen Aqualab supports the research programs of 26 faculty at the University (including two positions funded externally by the Great Lakes Fisheries Commission), and another 10 Principal Investigators from other institutions. Aqualab researchers exhibit an extraordinary level of research productivity, with 418 peer-reviewed publications from facility users to date. Importantly, the facility and the research conducted in it attract numerous partners from the government, private, and not-for-profit sectors, and enhances the recruitment and retention of world-class faculty. For example, in the last year alone, four new faculty (Alderman, Bernhardt, Huyben, Scott), whose research programs will directly benefit from the unique capabilities of the Aqualab, have been recruited.

The Hagen Aqualab also provides unique teaching and research opportunities for undergraduates and graduate students. For example, each year the Aqualab supports exceptional experiential learning for over 50 undergraduate students through 4th year projects courses, research assistantships, and co-op placements. Dozens of graduate

students also conduct research in the Aqualab each year, with 164 masters and doctoral theses produced to date. The Hagen Aqualab is an essential pillar in the mentoring of trainees, and hundreds of Aqualab alumni are now leaving their footprint across Canada and beyond in impactful positions in government, academia, industry and the not-for-profit sector. This extensive network of alumni has contributed to Aqualab receiving live specimens from across Canada, ranging from British Columbia and the Pacific Ocean, the Great Lakes, and Nova Scotia and the Atlantic Ocean. As a result, the Hagen Aqualab is strategically positioned to be a central component of Canada's ecology research, undoubtedly contributing to the University of Guelph's international recognition in ecology research by Times Magazine (top 50 programs in the world). At the same time, it is also emerging as key support for strengthening the University's footprint in the biomedical sciences.


$12M+
investment since its founding
~100
species held at any given time
418
peer-reviewed publications
25
years advancing aquatic research
160+
graduate theses
21
undergraduate courses
24
research and holding rooms
20
faculty
40
graduate students
33
donors
15
undergrad thesis & co-op students
15
volunteers
on average work in the Aqualab every year

HISTORY

A Pioneering Facility

The U of G has been a centre of expertise in aquatic sciences since the late 1960s, when Keith Ronald, then Dean of CBS, launched a marine biology program that immediately attracted prominent ichthyologists and environmental scientists. In recognition of its impressive roster of aquatic biologists, and with the aim of advancing research, teaching, and outreach in freshwater and saltwater systems, U of G created the Hagen Aqualab, named after Rolf Hagen, president of Montreal's Rolf C. Hagen Inc., Canada's largest pet store supplier at the time.

> "*This aquatic sciences facility at the University of Guelph will put Canada on the global map for aquaculture and water treatment.”*
> - Rolf Hagen, 1995.

The Hagen Aqualab, as well as the former Institute of Ichthyology (now part of the Department of Integrative Biology), were a $6 million endeavour made possible by an NSERC installation grant and several industry donors, including Hagen. Phase 1 of construction included all the central facilities (e.g., hot and cold glycol systems, regenerative air, water supply and treatment, computer control system, dry lab, freezer, access control, backup generator, high- and low-pressure steam). These occupied three quarters of the space in the Aqualab and enabled the study of all facets of aquatic sciences, hosting faculty and students with diverse research interests in freshwater and marine fish species, from the Arctic to the tropics, and across disciplines such as toxicology, nutrition, aquaculture, physiology, evolution, and ecology. Importantly, the new research capabilities created with the Hagen Aqualab were fully distinct from those available through the Alma Aquaculture Research Station (AARS), a facility located near Alma, Ontario (37 km from campus) that is managed through the U of G and Ontario Ministry of Agriculture, Food and Rural Affairs partnership program. More specifically, the Aqualab enables fundamental research that requires extensive use of recirculation systems and precise control of environmental variables, whereas the AARS supports applied, scale-able research on fish production and breeding for the aquaculture

industry that relies primarily on flow-through systems. The Aqualab was ultimately certified for animal holding in late 1995 and the first research project began in January 1996.

> *"Why invest more in aquatic sciences? There has never been a more important time for aquatic research in Canada, especially considering the collapse of the East Coast fishing industry... Aqualab will contribute to this effort both by targeting the development of protocols for the aquaculture of new species and by extending our general knowledge of aquatic organisms.*"
>
> - Paul Hebert, 1995.

Phase 2 of the Hagen Aqualab was completed in May 2001 thanks to a CFI grant matched by the Ontario Ministry of Colleges and Universities (MCU). This $4.3M grant lead by Glen Van Der Kraak also supported infrastructure at the Alma Aquaculture Research Station and Huntsman Marine Science Centre (St. Andrews, NB) and solidified the U of G's national leadership in the aquatic sciences.

The Hagen Aqualab was a pioneering facility in Canada. Other current and similar facilities in Canadian universities were modelled after the Aqualab, and Aqualab staff and faculty have served as consultants to guide the design of these other research spaces. These include the InSEAS system at UBC and the new aquatic facilities at the University of Waterloo, Wilfred Laurier University, McMaster University, University of Ottawa and the Center for Inland Waters (ECCC, Burlington). Amongst these facilities, the Hagen Aqualab remains a flagship facility in the aquatic sciences and the only non-coastal institution with saltwater capabilities, further contributing to the U of G's distinct identity in the academic sector.

Infrastructure and Operations Enhancement Over the Years

The Hagen Aqualab has been instrumental to the acquisition of research and infrastructure funding over the years. The CFI/MCU project that enabled the completion of Phase 2 of the Aqualab, titled “Enhancing Fish Performance: From Genes to Populations”, resulted in a total investment of over $2.1 million during the period 1999-2005 and provided the necessary infrastructure to propel research forward in the areas of biotechnology, genomics, toxicology, and one health.

Other CFI/MCU awards led to additional enhancements in the Aqualab, including a $266,000 award to Nicholas Bernier for the Laboratory for the Molecular Endocrinology and Physiology of Fish (2002), a $160,000 grant to John Dawson for investigations of F-actin in the Heart (2005), $480,000 to Todd Gillis and Doug Fudge to establish the Protein Dynamics Lab (2006), a $152,000 award to Terry Van Raay to establish the Zebrafish Laboratory for Development and Disease (2009), and a $227,000 award to Sarah Alderman (2022) to purchase a fluorescence activated cell sorter. Further, the Southern Ontario Water Consortium (SOWC) provided over $240,000 to Glen Van Der Kraak in funding for lab infrastructure for fish toxicology including real-time PCR, tanks, heaters, and water chemistry equipment. The NSERC Research Tools and Instruments Program has also invested $954,000 in supporting multiple applications for infrastructure to modernize and expand the research conducted in this research facility. This includes the purchase of a high frequency ultrasound to image cardiac function in live animals ($150,000 to Gillis, Dawson, Vickaryous, 2019), a Flexcell system to apply biomechanical forces to trout cardiac fibroblasts ($68,220 to Jones and Gillis, 2020), and a fluorescent microscope to study brain and heart development of zebrafish ($150,000 to Alderman, Bernier, Gillis, and Newman, 2022). Going forward, there is a CFI IF application under review, led by Van Der Kraak and McCann, that if successful will provide over $2 million to the Aqualab to expand capacity for regulating environmental conditions in large and small aquatic habitats. Such infrastructure (including oxygen monitors, chiller upgrades, among others) will increase our capacity to replicate the complex environmental changes

that are affecting fish and invertebrates due to human-induced pollution and climate change.

Sources of institutional funding have included U of G, CBS, and the Department of Integrative Biology. For example, U of G has made funds available from the Infrastructure Operating Fund (IOF), which provides funds to help support the operation of facilities established through CFI programs. The Department of Integrative Biology makes a significant yearly investment to support Aqualab operations including two permanent staff positions (e.g., $218,000 in 2020-21). Funds from the U of G's Office of Research and Physical Resources have further upgraded the Aqualab's infrastructure (e.g., LED lighting efficiency, door locks, chillers, and drum filters). Collectively, these investments have enabled the facility to remain state of the art and a resource for the campus and beyond. The operational income generated by the Hagen Aqualab —derived from room utilization charges, consumable cost recovery, and student labour reimbursement (work-study program)— amounts to $74,000-$95,000/year and fully covers the non-staffing related operational costs of the Aqualab. These operational costs include plumbing/maintenance/electrical supplies, aquatic system replacement parts, service contracts and calls, lab chemicals, communication, physical resources work orders, and vehicle charges. Any additional revenue from grants, campus units, and donors has been used to improve or expand the research capabilities of the Aqualab.

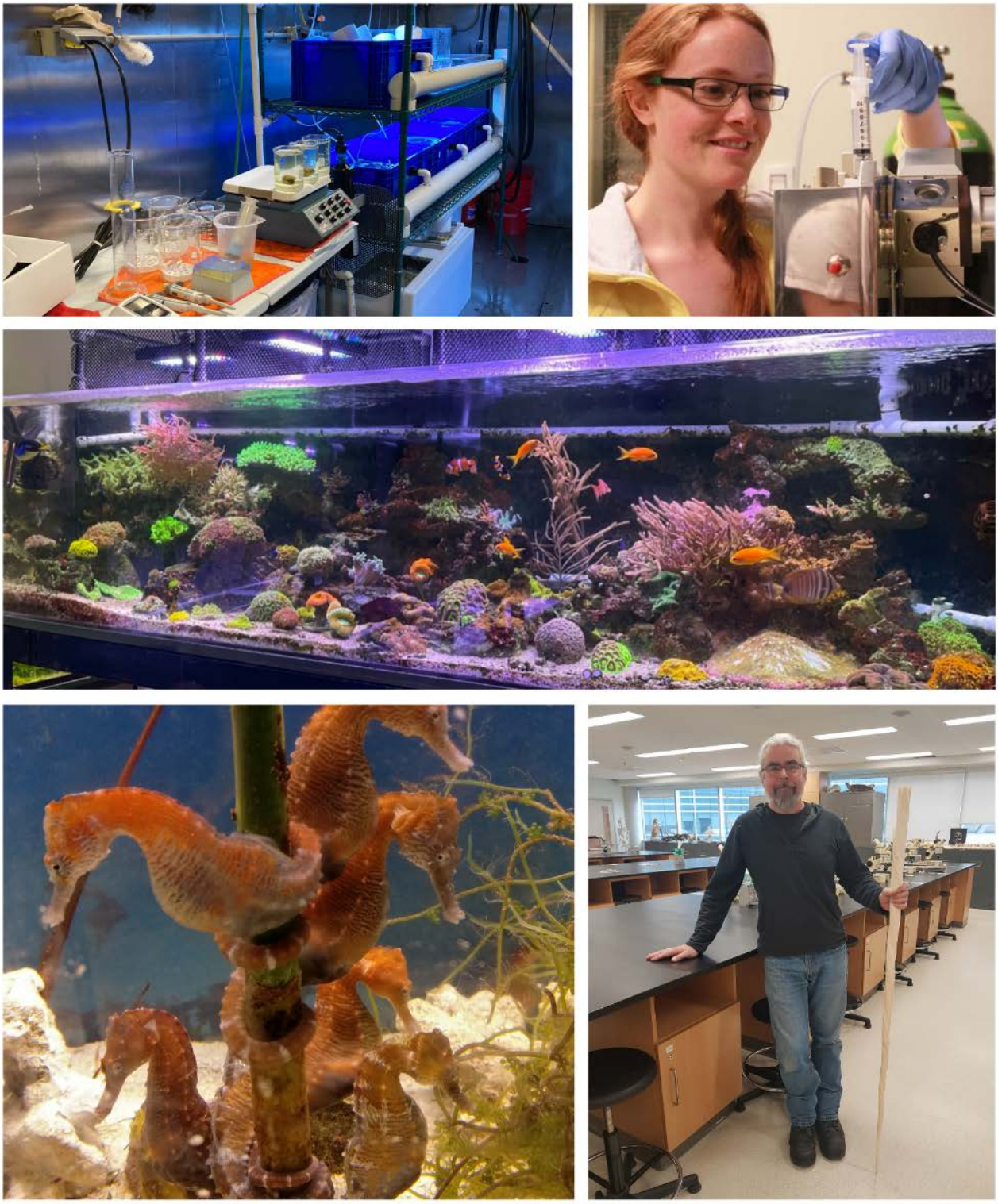

Figure 1. Researchers utilize *in vivo* and *in vitro* approaches to study aquatic species in the Aqualab. Matt Cornish (bottom right), Aqualab Coordinator, has been instrumental to this facility.

Dozens of donors, including individuals, companies, and foundations have generously donated to the construction and operation of the Hagen Aqualab:

- Alma Mater Fund
- Andres Wines
- Audrey S. Hellyer Charitable Foundation
- Barrick Gold
- Brascan Foundation
- Calona Wines Ltd.
- Canadian Hydrogardens Ltd.
- Catherine and Maxwell Meighen Foundation
- CBS Alumni Association
- Corby Distilleries Ltd.
- Dr. Ulric Baensch
- Ducks Unlimited
- Falconbridge
- Featherstone & Co.
- Gilbey Canada
- Henry N.R. Jackman Foundation
- Hiran Walker & Sons Inc.
- Imasco Ltd.
- Laidlaw International Inc.
- McLean Foundation
- Noranda Foundation
- Ontario Innovation Trust
- Pelee Island Winery
- Richard and Jean Ivey Foundation
- Rolf Hagen Inc.
- Seagram Company Ltd.
- TD Friends of the Environment
- Briks Family Foundation
- E.W. Brickle Foundation
- Harold Crabtree Foundation
- Mark Anthony Group
- R. Howard Webster Foundation
- TransCanada Pipelines

RESEARCH EXCELLENCE

Mission

The Hagen Aqualab's mission is to:

- Facilitate research on a variety of aquatic organisms, including microorganisms, animals, and plants from marine, brackish or freshwater habitats, which originate from arctic, temperate, or tropical climates.
- Foster the training of undergraduate and graduate students in advanced research techniques.
- Encourage interaction and collaboration among universities, government, and the private sector.

Research Infrastructure

The Hagen Aqualab is a technologically advanced, aquatic research facility utilized by researchers at U of G and beyond. The Aqualab was designed and engineered to provide maximum flexibility in all research space and was ahead of its time in employing recirculation technology to maintain water quality and reduce water consumption. Its various research rooms can accommodate projects of moderate size. More than 150 species have been held in Aqualab facilities since 1996 with an average range of 75-125 species held at any given time.

The Hagen Aqualab consists of 24 research and holding rooms with integrated recirculation systems that include computer-controlled pumps, filtration systems (screen and gravel bed), UV sterilization, humidity, photoperiod, and accurate temperature control. This ability to control and monitor real-world environmental conditions (e.g., temperature, photoperiod, salinity, and oxygen availability) is proving critical to multiple ongoing projects that seek to understand the consequences of current and future climates on the survival of aquatic species and ecosystems. This is essential in a context of global ecological change and climate crisis.

Aqualab systems include:

- Three research rooms with an integrated recirculation system and a single operating water temperature (Rms. 182, 184, and 185).
- One environmental chamber with an integrated recirculation system and a single operating water temperature (Rm. 183).
- Five research rooms with integrated recirculation systems and three operating water temperatures (Rms. 180, 186, 150, 152, and 154).
- One environmental chamber with flow-through system and three operating temperatures. This room has been modified for aquatic disease research and meets the requirements for Level-2 containment (Rm 156).
- One isolation room with a flow-through system that has been set up for experiments designed to study diseases in fish. This room also meets the requirements for Level-2 containment (Rm 155).

- One general holding room with an integrated recirculation system for 25 x 2m^3 tanks (Rm 160).
- Four environmental chambers at 20 m^2 each (Rms. 163, 165, 181, and 181a).
- Seven environmental chambers at 9 m^2 each (Rms. 160A-G).
- Twelve ECARS (Environmentally Controlled Aquatic Recirculating Systems) (Rms. 151A and B). These systems are essentially environmental chambers for water.

The Aqualab has a decentralized computer control system that controls, monitors, and alarms functions within the facility. Features include data logging, real-time monitoring, and alarming of all sensors (e.g., temperature, flow, water level, photoperiod, O_2, pH), control of devices that enable air and water flow (recirculated and make-up), photoperiod, and temperature control (both air and water). Photoperiod can be controlled on a daily basis to emulate sunrise and sunset for any global position.

All rooms are supplied with untreated well (raw/fresh) water, which is chlorine-free and therefore does not require expensive dechlorination technologies. This facility is salt water capable with five research rooms currently dedicated to marine animal holding and research. These marine rooms are utilized by undergraduate and graduate students and this capacity is novel to any Canadian university that is not located on a coast.

The Hagen Aqualab is supported by two full-time staff, one grant-funded research technician, and up to 15 student technicians per year.

Faculty Research Programs

To date, research supported by the Hagen Aqualab has focused primarily on salmonid fish, zebrafish and hagfish. However, faculty and students also work on reptile, amphibian, coral, sea urchin, freshwater mussel, and tropical fish research. Space has also been allocated to research on aquatic plants. The Aqualab supports, annually and on average, the work of 20-25 faculty, 40 graduate students, and over 50 undergraduate students, including those in the Marine and Freshwater Biology major and those who conduct undergraduate theses, complete co-op placements, or volunteer in the

Aqualab. While there are many researchers from the Department of Integrative Biology who use the Aqualab, there are many other academic units that use it consistently. These include Molecular and Cellular Biology, Pathobiology, Environmental Science, and Biomedical Science. For example, Dr. Matt Vickaryous' (BioMed) research program examining heart and spinal regeneration in geckos has been based out of the Aqualab for seven years and Dr. John Dawson (MCB), who utilizes zebrafish to study protein mutations that cause heart disease in humans, has a large presence in the Aqualab. A list of current and past faculty who use Aqualab is presented in Appendix 1.

Since its opening, the Hagen Aqualab has been an invaluable asset to dozens of research projects from nutrient and trophic dynamics to embryology and production, conservation and restoration, environmental adaptation, stress and metabolism, evolution and speciation, physiology and anatomy, biophysics, biomimetics, biomechanics, neurobiology, immunology, toxicology and risk assessment, and cancer research, among others.

Importantly, in addition to the applied research partnerships supported by the Aqualab that are described in the next section, the Aqualab also plays a fundamental role in supporting discovery-based research, primarily funded through the NSERC Discovery Grant program. Of the current Aqualab users on campus, 23 hold active Discovery Grants, with a total annual value of $865,000.

To date, research conducted in the Hagen Aqualab has resulted in 418 peer-reviewed publications (see Appendix 2). The Students Communicating Research in Biology Education (SCRIBE) program in CBS has also translated and helped disseminate some of the research projects supported by the Aqualab (e.g., "Low Oxygen Impairs Brain Development in Fish, but the Fish Aren't Stressed About It", "Fish Out of Water: an Unexpected Discovery").

Role in Attracting and Retaining Faculty

The research potential of the Hagen Aqualab has been instrumental in attracting and retaining faculty members who work on disciplines related to the aquatic sciences. The Aqualab provides not only state-of-the-art infrastructure within campus but also offers fee-for-use rooms and equipment, expert staff who monitor and control operations on a full-time basis, and a safe and familiar place for student training. Having this capacity in-house has allowed faculty to focus their efforts on research and student mentoring. As an example, since 2005, U of G has recruited >13 new faculty members working in aquatic physiology, toxicology or closely related fields, including eight in the Department of Integrative Biology, two in Molecular and Cellular Biology, one in the Ontario Agricultural College, and two in the Ontario Veterinary College.

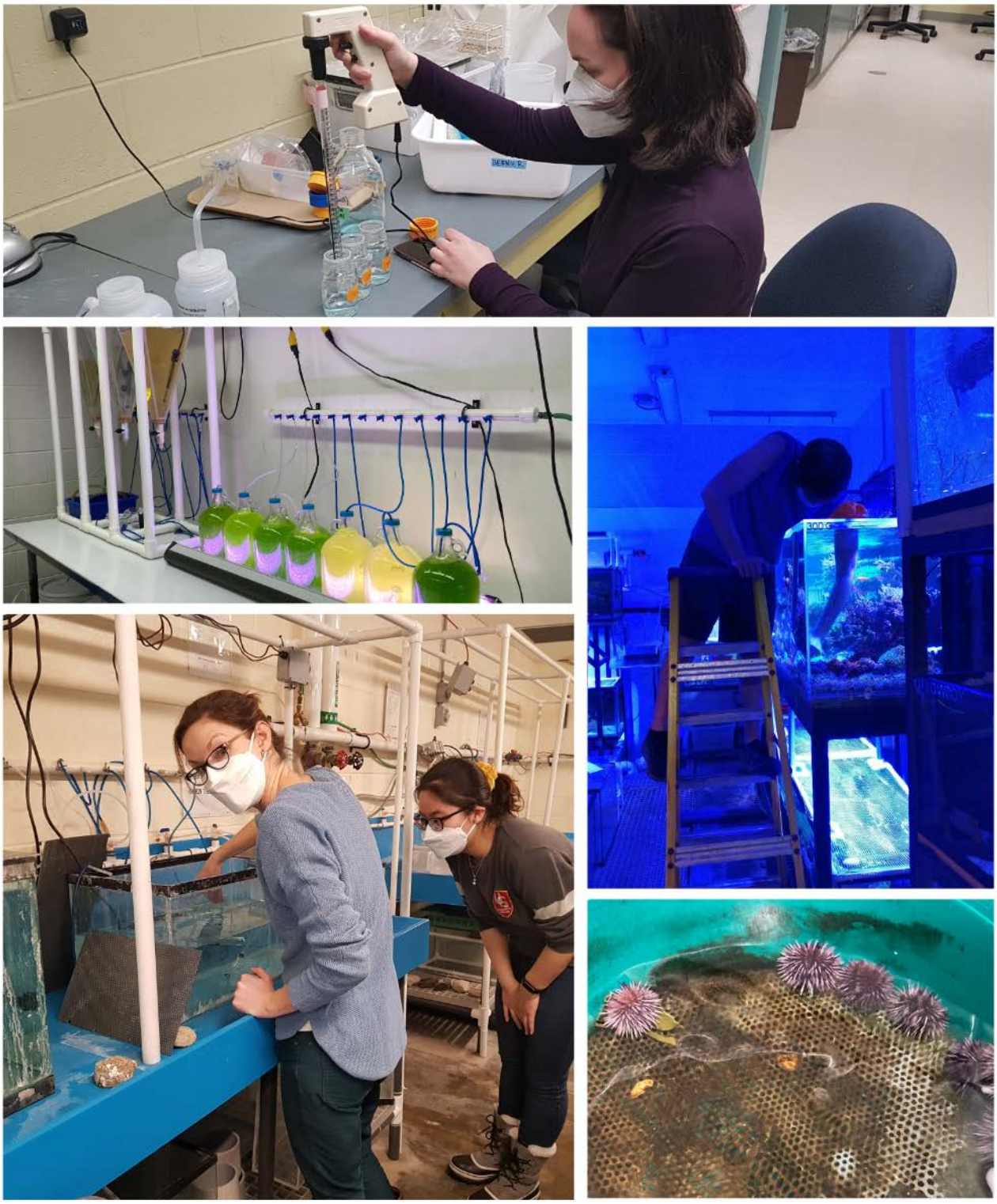

Figure 2. The Aqualab has been supporting the work of students such as Amanda Reside (top) and Drayke Evans (middle), Professor Sarah Alderman and student Chengcheng Zhang (bottom left).

RESEARCH PARTNERSHIPS

Research conducted in the Hagen Aqualab is critical to external partners locally, nationally, and internationally. Over the years, several government organizations, not-for-profits, and industry partners have been involved with research taking place in the Aqualab or otherwise supported Aqualab operations. While not exhaustive, the information below showcase some of the most noteworthy partnerships made possible by the Aqualab.

Government Partners

Fisheries and Oceans Canada has been an important partner in research related to the cardiac toxicity of bitumen from the Alberta Oil sands, as well as the identification of plasma biomarkers of cardiac stress in aquatic species. This research, while funded through DFO contracts and NSERC Engage grants, was also possible due to the contributions of Gryphon LAAIR program and Cedarlane Labs. In addition, the Government of Canada, through its Environmental Effects Monitoring Program, has supported the development of new regulations and operating conditions that are current standard for the pulp and paper sector. This partnership also included Canadian universities (Waterloo, Wilfrid Laurier, and Prince Edward Island) and the University of Santa Catarina in Brazil. Environment and Climate Change Canada has also funded research focused on the effects of fluorotelomer acids on zebrafish, and on the impacts of road salt, oils sands-derived effluents, and firefighting water additives on the early life stages of freshwater mussels. These collaborations led to further research support from Environment and Climate Change Canada; in this case, to explore the possibility of rearing mussels in the Aqualab for experiments and potentially re-introduction programs for those that are endangered.

At the provincial level, Aqualab users have partnered with 1) the Ontario Ministry of the Environment, Conservation and Parks for research on the impacts of municipal wastewater effluents in fish; 2) the Ontario Ministry of Natural Resources for research on

the brain development and behaviour of captive-reared brook charr; and, 3) the Ontario Ministry of Agriculture, Food, and Rural Affairs to investigate feed ingredients (insects and probiotics) on zebrafish as a model for farmed fish. This partnership also included the participation of feed companies, namely Enterra and Alltech, and leveraged funding through the NSERC Alliance program.

Environment Canada, the Ontario Ministry of the Environment, the Grand River Conservation Authority, the Region of Waterloo, and the City of Guelph partnered with U of G researchers through the NSERC Strategic Project Grant program to understand the response of fish to infrastructure upgrades at municipal wastewater treatment plants.

The Great Lakes Fishery Commission (GLFC), a binational commission between Canada and the United States, has been a longstanding and valuable partner for aquatic research at U of G. Since 2002, they have funded a faculty position in Integrative Biology, and in 2022 began funding a second position, with additional funds provided to support administration and research events. Over the last 5 years alone, GLFC investment has totaled approximately $1.2 million. Research projects supported to date include 1) lampricides and their impact on the reproductive health of fish, 2) mass marking of sea lamprey, and 3) genetic and environmental influences on the brain morphology of stream-resident and migratory brook charr.

Not-for Profit and Community Partners

The Canadian Water Network has actively supported work on the reproductive response of fish, with direct relevance for the municipalities of Guelph, Kitchener, and Waterloo and for the Grand River Conservation Authority. Another large not-for-profit partner was FP Innovations (formerly the Pulp and Paper Research Institute of Canada), which supported numerous experiments and graduate students working on the impacts of pulp and paper mill effluents on fish.

Faculty who make use of the Aqualab have also partnered with the Heiltsuk First Nation in British Columbia, with funding from NSERC Alliance, to investigate the impact of

petroleum hydrocarbons and polycyclic aromatic hydrocarbons on different species of marine bivalves that have cultural, ecological, and commercial importance to their Nation. Currently, Genome Canada is supporting the Genomic Network for Fish Identification, Stress and Health, a national team of researchers, professionals, and community-members who are working to determine the location and abundance of Canada's 200+ freshwater fish species, and to measure how they are performing in the face of increasing stressors.

Industry Partners

Aqualab users have formed partnerships with Syngenta to examine the effects of herbicide atrazine on fish and amphibians, as well as with Suncor to investigate oil sands process-affected waters. Shell Canada Energy, Canadian Natural Resources Ltd., Imperial Oil Ltd., Suncor Energy Inc., Syncrude Canada Ltd., and Total E&P Canada (with support from the Canadian Water Network and funding from NSERC) were part of research that assessed the impacts of naphthenic acids on aquatic organisms. Notably, the John Lumsden's lab has collaborated with Ripley's Aquarium of Canada in research projects on seahorse health and aquaculture, coral regeneration, and jellyfish physiology.

Funding from NSERC Strategic Project Grants has also been leveraged through a variety of partnerships with industry, sometimes in collaboration with government or not-for-profits. Some of these included: 1) Leadley Environmental Corp., Environment Canada and the Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry in relation to the physiological responses of Detroit River bullhead populations to aquatic contaminants; 2) Lyndon Fish Hatcheries and Aqua-Cage Fisheries in relation to projects aimed at optimizing the development of broodstock for the Ontario rainbow trout aquaculture industry; 3) Yellow Island Aquaculture for improving the hatchery performance of Chinook salmon in British Columbia; and, 4) Cedarlane Labs and Gryphon LAAIR for the development of diagnostic tools for the aquaculture industry.

COMMUNITY ENGAGEMENT AND OUTREACH

Staff in the Hagen Aqualab have participated in and supported a variety of community engagement and outreach programs over the years. In a typical year, over 100 people with diverse interests and backgrounds visit the Aqualab. Some examples of community engagement and outreach activities the Aqualab has hosted in the last few years are:

- Educational groups:
    - High school tours: Georgetown District High School, Guelph Collegiate and Vocational Institute, Catholic Central High School (London), Bishop Macdonell (Guelph), Our Lady of Lourdes (Guelph), St. James (Guelph), Pauline Johnson Collegiate and Vocational School (Brantford), and Paris District High School (Paris).
    - Elementary school tours: École élémentaire catholique Saint-René-Goupil (Guelph), St. John's Kilmarnock (Waterloo), Victory School (Guelph).
    - Ranger programs: Mill Creek and Ontario Ministry, including visiting scientists and prospective graduate students.
    - U of G events: Orientation Week tours (Marine and Freshwater Biology club), College Royal (Marine and Freshwater Biology club display), Science and Engineering Sunday (tours), U of G Canadian Association for Girls in Science, U of G Creative Encounters, U of G BSc. Program Counsellors (recruitment event), U of G Interactions Conference.
- Dignitaries: The Honourable Ed Holder, Federal Minister of State (Science and Technology).
- Professional networking: Wilfrid Laurier's Centre for Cold Regions and Water Science; Bonne Bay Marine Station, NL; McMaster University; Churchill Northern Studies Centre; Cape Breton University; Environment Canada; OMAFRA Aquaculture scientists, Pond Perfections Inc. (Mildmay, Ontario), University of Wisconsin-Stevens Point; Central Animal Care Facility, University of Windsor; College of Fisheries, Huazhong Agricultural University; Guelph Lake Nature Centre.

Figure 3. Expert staff like Mike Davis (top right), Aqualab Assistant Coordinator, enable learning experiences for students like Jenica Pires (top left) as well as the collection of marine species from St. Andrews NB for undergraduate projects in Guelph.

HQP TRAINING

Undergraduate Teaching Support

The Aqualab is a hands-on learning space that provides students with the opportunity to conduct experiments in a real research facility, simulate global aquatic environments, observe and help with the rearing of different types of aquatic organisms, and acquire specific knowledge and skills for aquarist, aquaculturist, and aquatic roles. Aqualab support for undergraduate courses ranges from advising and building and/or assisting in research project setups to providing logistical support for thesis and lab-based courses, offering animal husbandry consultation, and supplying and maintaining live animal collections and equipment. For example, during each of the last 25 years, approximately 20 fourth-year students in the Marine and Freshwater Biology Program have completed individual research projects in the Aqualab for course credit. This work, completed using a variety of marine or freshwater animals (> 125 species), is a capstone for this program. Through this one course alone, the Aqualab has provided experiential learning opportunities for ~ 500 undergraduate students. The popularity of the Marine and Freshwater Biology program has also been growing in the last five years. This program currently has 160 students across all four years (regular and co-op) and 70 new students joined the incoming cohort for the academic year 2022-23. Overall, the Aqualab is uniquely positioned to enhance training in the aquatic sciences and to provide a sound scientific background for students pursuing careers in biology, management and conservation, aquaculture, biotechnology, education, and research in either government or private sectors.

In the last few years, the Hagen Aqualab provided experiential learning opportunities for the following undergraduate courses:

- BIOM*4521/22 Research in Biomedical Sciences 1 & 2
- IBIO*4500/10 Research in Integrative Biology 1 & 2
- IBIO*4521/22 Thesis in Integrative Biology 1 & 2
- IBIO*4600 Integrative Marine and Freshwater Research

- MCB*4510 Research Project in Molecular and Cellular Biology
- NEUR*4450 Research in Neurosciences
- NEUR*4401/2 Research in Neurosciences
- PATH*4100 Diseases of Aquatic Animals
- SART*4660/70 Topics in Extended Practices 1 & 2
- ZOO*2700 Invertebrate Morphology and Evolution
- ZOO*3050 Developmental Biology
- ZOO*3200 Comparative Animal Physiology 1
- ZOO*3210 Comparative Animal Physiology 2
- ZOO*3610 Lab Studies in Animal Physiology 1
- ZOO*3630 Lab Studies in Animal Physiology 2
- ZOO*3700 Integrative Biology of Invertebrates
- ZOO*4070 Animal Behaviour
- ZOO*4170 Experimental Comparative Animal Physiology
- ZOO*4300 Marine Biology and Oceanography Field Course
- ZOO*4330 Biology of Fishes
- ZOO*4520 Thesis in Integrative Biology
- ZOO*4940 Lab Studies in Herpetology

Graduate Studies Support

There is an increasing demand for highly qualified personnel in various sectors related to the aquatic sciences and this includes environmental consulting firms, governmental (federal, provincial), biomonitoring labs, and biotech industries. The Aqualab plays a key role in providing students with access to modern instruments that can be applied to the study of ecosystem, communities, populations, individuals, and genomes. Graduate students who use the Aqualab for their research can hone their leadership, critical thinking, statistical, project management, and communication skills while also receiving mentorship from expert faculty and staff. The Aqualab also provides opportunities to learn and practice unique techniques that would not be possible without the available

infrastructure and equipment. This includes the use of high frequency ultrasound to monitor cardiac function in live animals, including zebrafish. The convenient location of the facility has also been an important advantage for graduate students at U of G and neighbouring universities, as it provides ease and flexibility for the scheduling of experiments. The proximity of the Aqualab to the Summerlee Science Complex also allows for delicate tissues to be quickly transported to research labs for experimentation in any weather. The value of the Aqualab for graduate research is evidenced by the more than 160 graduate theses that have been completed in this facility (Appendix 3).

Alumni Destinations

Undergraduate and graduate students who have trained in the Aqualab now have a unique footprint in various academic and non-academic sectors, and while many have found fulfilling roles across Canada, others have taken their expertise to the international stage. Examples of over 100 alumni destinations are shown in Appendix 4. Some popular career pathways include aquatic scientist, researcher, and technician positions in the government (e.g., Health Canada; Fisheries and Oceans Canada; Canadian Food Inspection Agency; Agriculture and Agri-Food Canada; Environment and Climate Change Canada; Parks Canada; Ontario Ministry of the Environment, Conservation, and Parks; Ontario Ministry of Northern Development, Mines, Natural Resources, and Forestry; Cawthron Institute of New Zealand) or consulting firms (e.g., Ecological Logistics and Research Ltd., Minnow Environmental Inc., Environmental Resource Management, AquaTox Testing and Consulting Inc., among others).

Aqualab alumni have also made a significant impact in the conservation and welfare of marine and freshwater biodiversity through their positions at several not-for-profit or research organizations. Some examples include the Toronto Zoo, Oceana, Whale and Dolphin Conservation, Ocean Wise Conservation Association, and Ottawa Riverkeeper. Careers in data management and analytics, as well as bioinformatics and biotechnology, have also been a common choice of alumni, further demonstrating the diversity of career interests and paths.

Alumni trained in the Aqualab have also continued to further their studies through graduate degrees, including some who pursued veterinary medicine. Those who have followed an academic path are currently pursuing postdoctoral work or have secured faculty and lecturer positions in postsecondary institutions such as U of G, University of Waterloo, Wilfrid Laurier University, Harvard University, Brock University, Washington State University, University of New Brunswick, University of California Davis, Simon Fraser University, Douglas College, Cape Breton University, University of Aberdeen, University of Glasgow, and Ohio State University. Several alumni have pursued positions in science communication and knowledge translation such as scientific writing, STEAM education, nature photography, storytelling, design and communications coordination, negotiation and liaison with stakeholders, and partnership building.

UNIVERSITY PRIORITIES AND INTERNATIONAL REPUTATION

Supporting U of G Priorities

The work of the Aqualab in both research and teaching has been highly significant to the advancement of numerous U of G priorities, as well as initiatives and institutes across campus. The Aqualab is central to three of the strategic themes of the University's new Strategic Research Plan (SRP) 2023-2028: 1) *Fundamental Discovery*, 2) *One Health*, and 3) *The Environment*. Importantly, these areas are widely recognized as longstanding strengths at U of G and are expected to be consistent and prominent foci in future iterations of the SRP as well. The Aqualab advances our understanding of the parameters that shape the health and wellbeing of diverse organisms from molecular to ecosystem scales, promotes the sustainable stewardship of natural and human systems, and informs practices and policies for secure and responsible agricultural and food systems.

The Hagen Aqualab's mission is aligned with the emerging area of One Health, connecting animal, human, and environmental wellbeing under one holistic study

framework. The research and teaching efforts of the Aqualab complement other One Health initiatives launched at U of G such as the creation of the One Health Institute, the development of a new Bachelor's degree in One Health, and the allocation of faculty lines to this research area. For example, work by Dr. Sarah Alderman is examining how environmental stressors, including social stressors, affect brain development and neurogenesis.

Biodiversity is also a long-standing and critical research area at U of G that has received consistent support from the Aqualab. In CBS alone, 31 faculty identify biodiversity as a key focus of their research program, and at least 15 of them use the Aqualab on a regular basis. Faculty and students working in the Aqualab typically collaborate with researchers in the Biodiversity Institute for Conservation Synthesis, the Centre for Biodiversity Genomics, and the Guelph Institute for Environmental Research, highlighting the Hagen Aqualab's role in promoting synergy across colleges.

Synergies between the Hagen Aqualab and the Ontario Agri-Food Innovation Alliance (formerly known as the OMAFRA-U of G Partnership) have enriched this research collaboration effort between the Ontario Ministry of Agriculture, Food and Rural Affairs and U of G. The Aqualab has enabled experimentation and simulation research in the areas of aquaculture, toxicology, and impact assessment with relation to agricultural practices. As such, the Hagen Aqualab plays an important role in advancing research and innovation and fostering multidisciplinary research collaborations at the provincial level. The Hagen Aqualab's capacity in aquatic toxicology also complements the recent Canada First Research Excellence Fund awarded to U of G for the Food from Thought university-wide project. More specifically, the Aqualab has supported aquatic toxicology research to test the consequences, and ultimately the remediation, of aquatic contaminant exposures in fish. As a current example, Drs. John Fryxell and Rene Shahmohamadloo are examining the impact of agricultural run off on aquatic ecosystems in the Great Lakes.

International Frameworks for Sustainability

The Hagen Aqualab's mission aligns with two of the most pressing sustainability needs identified by the United Nations as part of their Sustainability Development Goals (SDGs) framework: Clean Water and Sanitation (Goal 6) and Life Below Water (Goal 14). Goal 6 is currently supported by the Aqualab through ecotoxicological testing and water quality research that inform decision-making and policy as the levels of contaminants entering waterways and contributing to water quality deterioration grow rapidly across the globe. With regards to Goal 14, the Aqualab is the research space of choice for whole animal testing and allows for the study of key developmental landmarks such as sexual differentiation, puberty, reproductive success, and fitness of the next generation, as well as the simulation of changing aquatic environments and their impact on the biology and conservation of aquatic organisms.

International Rankings

U of G's excellence and reputation in biological sciences, animal and plant sciences, and environmental/ecological sciences is well supported by the Hagen Aqualab. In 2022, U of G ranked:

- #6 in the EduRank Best Universities World Rank: Animal Science
- #37 in the EduRank Best Universities World Rank: Zoology
- #47 in the EduRank Best Universities World Rank: Wildlife and Fisheries Management and Conservation
- #51-75 in the Shangai Global Ranking of Academic Subjects: Ecology
- #59 in the Best Global Universities US News: Plant and Animal Science
- #138 in the Best Global Universities US News: Environment/Ecology
- #101-140 in the QS World University Rankings by Subject: Anatomy and Physiology
- #151-200 in the QS World University Rankings by Subject: Environmental Sciences
- #501-600 in the Times Higher Education Global Rankings: Biological Sciences

Figure 4. Professor John Dawson (top left) and students Jessica Collier (top right) and Elizabeth Manchester (bottom right) use some of the 24 research rooms of the Aqualab.

FUTURE DIRECTIONS

Research conducted in the Aqualab is currently making major contributions to our fundamental understanding of the effects of global change (e.g., increases in water temperatures, eutrophication, pharmaceutical build-up in municipal sewers) on natural ecosystems and their connection to human and animal health. Moving forward, the Hagen Aqualab will continue to support leading edge research on some of the most pressing challenges facing the world today that are rooted in sustainability, global change, and One Health. Key to the past and future success of the Aqualab is the ability to concurrently manipulate multiple environmental conditions at different scales and with consistent water quality that is chlorine-free and devoid of external stressors. This capability provides a unique facility for U of G scientists to design and undertake leading edge environmental experiments that replicate real world conditions.

Recent faculty hires have strengthened the critical mass of researchers at U of G in aquatic ecology, toxicology, physiology, and biomedical science. These faculty bring complementary and relevant expertise that is advancing our understanding of the complex interactions between animals and the environment, positioning the Aqualab to make even greater contributions in diverse areas of study moving forward. The recently established Centre for Ecosystem Management, supported through a large investment by the Great Lakes Fishery Commission, as well as the currently submitted CFI-IF proposal for $14 million, are testaments to the expertise in aquatic and related sciences at U of G and highlight the potential of the Aqualab to enable and/or strengthen other external partnerships in the future.

In the human health sphere, the Aqualab has become essential infrastructure for biomedical research at the U of G. This is due in large part to the increasing use of zebrafish as a practical and effective model to study multiple human pathologies. Faculty currently using zebrafish for biomedical research include Alderman and Bernier (stress and brain development), Dawson (familial cardiomyopathy), Gillis (heart regeneration), Scott (spinal cord regeneration), Van Der Kraak, (endocrine disruption and reproduction), and van Raay (cancer; role of microbiomes in neural development). A breeding facility

was recently established in the Aqualab to help meet the demand for quality zebrafish for both research and teaching at U of G, and to support the growing demand for zebrafish by the wider research community throughout Southern Ontario, an initiative that is expected to grow our collaborative networks and international reputation. Such use of zebrafish is expected to increase as more tools and approaches continue to be developed for this valuable animal model of disease. The significant resources of the Aqualab and its ability to provide stable aquatic conditions has put Guelph on track to become a major center for zebrafish research in Ontario, and further strengthen the University's footprint in the biomedical sciences and ability to attract health-related research funding.

In addition to being a world-class research facility, the Hagen Aqualab also has a well-earned reputation as an outstanding training environment for graduate and undergraduate students. Thus, the Aqualab will continue to play a central role in attracting excellent trainees and supporting graduate program growth in areas of strategic importance to the University (e.g., collaborative specializations in One Health and neuroscience). The Hagen Aqualab remains the premier aquatic research facility in Canada and will continue to position the U of G as a recognized leader in environmental and ecological research across Canada and internationally, while also supporting strategic growth in the biomedical sciences.

APPENDIX 1- PAST AND CURRENT AQUALAB USERS

*active users in the last three years.

Integrative Biology

1. Ackerman, Josef*
2. Alderman, Sarah*
3. Ballantyne, Jim
4. Bernhardt, Joanna*
5. Bernier, Nicholas*
6. Bogart, Jim*
7. Brooks, Ronald
8. Boulding, Elizabeth*
9. Danzmann, Roy*
10. Ferguson, Moira
11. Fryxell, John*
12. Fu, Jinzhong*
13. Fudge, Douglas
14. Gillis, Todd*
15. Heyland, Andreas*
16. Laberge, Frederic*
17. MacDonald, Gord
18. Mason, Georgia*
19. McAdam, Andrew
20. McLaughlin, Robert*
21. Noakes, David Lloyd George
22. Robinson, Beren*
23. Stevens, E.D.
24. Van Der Kraak, Glen*
25. Wood, P.K.T
26. Wright, Patricia*

Molecular and Cellular Biology

27. Dawson, John*
28. Scott, Angela*
29. Stevenson, Roselynn
30. Van Raay, Terry*

Other Colleges

31. Ahmed, Wael *, Engineering
32. Huyben, David*, Animal Biosciences
33. Karrow, Niel*, Animal Biosciences
34. Lumsden*, S. John, Pathobiology
35. Prosser*, Ryan, Environmental Science
36. Rooney*, Neil, Environmental Science
37. Sibley*, Paul, Environmental Sciences
38. Solomon, Keith, Environmental Sciences
39. Vickaryous*, Matthew, Biomedical Sciences

Outside U of G

40. Beriault, Karine, OMNR, Huron Perth Area
41. Dixon, Brian, University of Waterloo*
42. Servos, Mark, University of Waterloo*
43. Fitzsimmons, John, Fisheries and Oceans, CCIW Burlington
44. Gillis, Patty, Environment and Climate Change Canada, CCIW Burlington*
45. Hart, Chris, OMNR, Clifton, ON
46. Milligan, Louise, Western University
47. Ripley's Aquarium of Canada*
48. Vijayan, Matt, University of Calgary
49. Vlassman, Kara, OMNR, Vineland Station, ON

APPENDIX 2- PEER-REVIEWED PUBLICATIONS

2020-present

1. Allore, C. A., Rossi, G. S., & Wright, P. A. 2021. Seeing in the swamp: hydrogen sulfide inhibits eye metabolism and visual acuity in a sulfide-tolerant fish. Biology Letters, 17(9), 20210329.
2. Ashpole, S. L., & Nikolenko, S. A. 2021. Note on the occurrence of twinning in Common Snapping Turtles (Chelydra serpentina) from the Great Lakes region of North America. Herpetology Notes, 14, 1437-1440.
3. Austin, L. E., Graham, C., & Vickaryous, M. K. 2022. Spontaneous neuronal regeneration in the forebrain of the leopard gecko (Eublepharis macularius) following neurochemical lesioning. *Developmental Dynamics*.

4. Baker, S. J., & Van Der Kraak, G. 2021. ADAMTS1 is regulated by the EP4 receptor in the zebrafish ovary. General and Comparative Endocrinology, 311, 113835.
5. Baker, S. J., Corrigan, E., Melnyk, N., Hilker, R., & Van Der Kraak, G. 2021. Nuclear progesterone receptor regulates ptger4b and PLA2G4A expression in zebrafish (Danio rerio) ovulation. General and Comparative Endocrinology, 311, 113842.
6. Balmori-Cedeno, J., Pham, P. H., Liu, J. T., Misk, E., Ryerse, I., Renshaw, S., ... & Lumsden, J. S. 2022. Autophagy-related gene regulation in liver and muscle of rainbow trout (Oncorhynchus mykiss) upon exposure to chloroquine, deoxynivalenol and nutrient restriction. *Aquaculture Research*.
7. Bradley, S. S., Howe, E., Bailey, C. D., & Vickaryous, M. K. 2021. The dendrite arbor of Purkinje cells is altered following to tail regeneration in the leopard gecko. Integrative and Comparative Biology, 61(2), 370-384.
8. Bradley, S. S., Howe, E., Bent, L. R., & Vickaryous, M. K. 2021. Cutaneous tactile sensitivity before and after tail loss and regeneration in the leopard gecko (Eublepharis macularius). Journal of Experimental Biology, 224(5), jeb234054.
9. Brown, T., Evans, D., Millar, Z., Pham, P., LePage V. and Lumsden, J.S. 2020. Fusarium solani haplotype 12-b and aortic and branchial arteritis in Hippocampus erectus Perry. Journal of Fish Diseases. 43(2): 301-304. DOI: https://doi-org.subzero.lib.uoguelph.ca/10.1111/jfd.13099.
10. Cochrane, P. V., Jonz, M. G., & Wright, P. A. 2021. The development of the O2-sensing system in an amphibious fish: consequences of variation in environmental O2 levels. *Journal of Comparative Physiology B*, *191*(4), 681-699.
11. Cox, G.K. & Gillis T.E. 2020. Surviving anoxia: the maintenance of energy production and tissue integrity during anoxia and reoxygenation. Journal of Experimental Biology. 223: jeb207613
12. Ding, Y., Johnston, E. F., & Gillis, T. E. 2022. Mitogen-activated protein kinases contribute to temperature-induced cardiac remodelling in rainbow trout (Oncorhynchus mykiss). *Journal of Comparative Physiology B*, *192*(1), 61-76.
13. Donato, S. V., & Vickaryous, M. K. 2022. Radial Glia and Neuronal-like Ependymal Cells Are Present within the Spinal Cord of the Trunk (Body) in the Leopard Gecko (Eublepharis macularius). *Journal of Developmental Biology*, *10*(2), 21.
14. Dong, Y. W., Blanchard, T. S., Noll, A., Vasquez, P., Schmitz, J., Kelly, S. P., ... & Whitehead, A. 2021. Genomic and physiological mechanisms underlying skin plasticity during water to air transition in an amphibious fish. Journal of Experimental Biology, 224(2), jeb235515.
15. Evans, D., Millar, Z., Wolvin, S., Pham, P. H., LePage, V., & Lumsden, J. S. 2021. Magnesium concentration influences size and pulse rate in the upside-down jellyfish, Cassiopea andromeda. Zoo Biology, 40(5), 472-478.
16. Fudge, D. S., Ferraro, S. N., Siwiecki, S. A., Hupé, A., & Jain, G. 2020. A New Model of Hagfish Slime Mucous Vesicle Stabilization and Deployment. Langmuir, 36(24), 6681-6689.

17. Fung, V. and Ackerman, J.D. 2020.The effects of river algae and porewater flow on the feeding of juvenile mussels. Journal of Geophysical Research: Biogeosciences. 125(1): e2019JG005302.
18. Graetz, S., Ji, M., Hunter, S., Sibley, P. K., & Prosser, R. S. 2020. Deterministic risk assessment of firefighting water additives to aquatic organisms. Ecotoxicology, 29(9), 1377-1389.
19. Johnson, E.F., & Gillis, T.E. 2022. Regulation of collagen deposition in the trout heart during thermal acclimation. Current Research in Physiology. 5: 99-108.
20. Johnston, E.F. and Gillis, T.E. 2020. Short-term cyclical stretch phosphorylates p38 and ERK1/2 MAPKs in cultured fibroblasts from the hearts of rainbow trout, Oncorhynchus mykiss. Biology Open. 9(1). pii: bio049296. DOI: 10.1242/bio.049296.
21. Liu, J. T., & Lumsden, J. S. 2021. Impact of feed restriction, chloroquine and deoxynivalenol on viral haemorrhagic septicaemia virus IVb in fathead minnow Pimephales promelas Rafinesque. Journal of Fish Diseases, 44(2), 217-220.
22. Liu, J. T., Pham, P. H., & Lumsden, J. S. 2022. Autophagy modulation in rainbow trout Oncorhynchus mykiss L. and resistance to experimental infection with Flavobacterium psychrophilum. *Journal of Fish Diseases*, *45*(4), 535-545.
23. Luck, K., & Ackerman, J. D. 2022. Threats to freshwater mussels: The interactions of water temperature, velocity and total suspended solids on ecophysiology and growth. *Science of The Total Environment*, *821*, 153101.
24. Mikloska, K. V., Zrini, Z. A., & Bernier, N. J. 2022. Severe hypoxia exposure inhibits larval brain development but does not affect the capacity to mount a cortisol stress response in zebrafish. *Journal of Experimental Biology*, *225*(2), jeb243335.
25. Peters, H., Laberge, F., & Heyland, A. 2022. Latent effect of larval rearing environment on post-metamorphic brain growth in an anuran amphibian. *Zoology*, *152*, 126011.
26. Ridgway, M. R., Tunnah, L., Bernier, N. J., Wilson, J. M., & Wright, P. A. 2021. Novel spikey ionocytes are regulated by cortisol in the skin of an amphibious fish. Proceedings of the Royal Society B, 288(1965), 20212324.
27. Rossi, G. S., & Wright, P. A. 2021. Does leaving water make fish smarter? Terrestrial exposure and exercise improve spatial learning in an amphibious fish. Proceedings of the Royal Society B, 288(1953), 20210603.
28. Rossi, G. S., Labbé, D., & Wright, P. A. 2022. Out of water in the dark: Plasticity in visual structures and function in an amphibious fish. *Journal of Experimental Zoology Part A: Ecological and Integrative Physiology*, *337*(7), 776-784.
29. Rossi, G.S., Wright, P.A. 2020. Hypoxia-seeking behaviour, metabolic depression, and skeletal muscle function in an amphibious fish out of water. Journal of Experimental Biology. 223: jeb213355. DOI: 10.1242/jeb.213355.
30. Shaftoe J.B., Manchester, E., & Gillis T.E. 2022. Cold acclimation followed by warm acclimation causes reversible cardiac remodeling in zebrafish (Danio rerio) Journal of Experimental Biology, submitted 2022 submission # JEXBIO/2022/245236.

31. Tunnah, L., Turko, A. J., & Wright, P. A. 2022. Skin ionocyte density of amphibious killifishes is shaped by phenotypic plasticity and constitutive interspecific differences. *Journal of Comparative Physiology B*, 1-11.
32. Tunnah, L., Wilson, J. M., & Wright, P. A. 2022. Retention of larval skin traits in adult amphibious killifishes: a cross-species investigation. *Journal of Comparative Physiology B*, 1-16.
33. Turko, A. J., Cisternino, B., & Wright, P. A. 2020. Calcified gill filaments increase respiratory function in fishes. Proceedings of the Royal Society B, 287(1920), 20192796.
34. Tuttle-Raycraft, S., & Ackerman, J. D. 2020. Evidence of phenotypic plasticity in the response of unionid mussels to turbidity. Freshwater Biology, 65(11), 1989-1996.
35. Whittaker, B. A., Maeda, S., & Boulding, E. G. 2021. Strike a pose: Does communication by a facultative cleaner fish, the cunner wrasse (Tautogolabrus adspersus), facilitate interaction with Atlantic salmon (Salmo salar)?. Applied Animal Behaviour Science, 236, 105275.
36. Williams, T.A. and Bernier, N.J. 2020. Corticotropin-releasing factor protects against ammonia neurotoxicity in isolated larval zebrafish brains. Journal of Experimental Biology. 223: jeb211540. DOI: 10.1242/jeb.211540.

2015-2019

37. Alderman, S.L., Leishman, E.M., Fuzzen, M.L.M. and Bernier N.J. 2018. Corticotropin-releasing factor regulates caspase-3 and may protect developing zebrafish from stress-induced apoptosis. General and comparative Endocrinology. 265: 207-213. DOI: 10.1016/j.ygcen.2018.05.025.
38. Avey, S.R., Ojehomon, M., Dawson, J.F. and Gillis, T.E. 2018. How the expression of green fluorescent protein and human cardiac actin in the heart influences cardiac function and aerobic performance in zebrafish Danio rerio. Journal of Fish Biology. 92(1):177-189. DOI: 10.1111/jfb.13507.
39. Baker, S. J.C and Van Der Kraak, G.J. 2019. Investigating the role of prostaglandin receptor isoform EP4b in zebrafish ovulation. General and Comparative Endocrinology. 283: 113228. DOI: 10.1016/j.ygcen.2019.113228.
40. Bernards Jr., M.A., Schorno, S., McKenzie, E., Winegard, T.M., Oke, I., Plachetzki, D. and Fudge, D.S. 2018. Unraveling inter-species differences in hagfish slime skein deployment. Journal of Experimental Biology. 221: 1-11. DOI: 10.1242/jeb.176925.
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42. Blanchard, T.S., Whitehead, A., Dong, Y.W. and Wright, P.A. 2019. Phenotypic flexibility in respiratory traits is associated with improved aerial respiration in an

amphibious fish out of water. Journal of experimental Biology. 222. doi: 10.1242/jeb.186486.
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44. Boggett, S., Stiles, J.L., Summers, A.P. and Fudge, D.S. 2017. Flaccid skin protects hagfishes from shark bites. Journal of The Royal Society Interface. 14(137): 20170765. DOI: https://doi.org/10.1098/rsif.2017.0765.
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46. Chaudhary, G., Fudge, D.S., Macias- Rodriguez, B. and Ewoldt, R.H. 2018. Concentration-independent mechanics and structure of hagfish slime. Acta Biomaterialia. 79: 123-134. DOI: https://doi.org/10.1016/j.actbio.2018.08.022.
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APPENDIX 3- GRADUATE THESES

2020-present

1. Axelrod, C. J. (2020) (PhD). Ecological effects on brain form in adaptively diverging sunfish.
2. Badlani, Y. (2021) (PhD). Characterization of miRNAs in full grown follicles in the zebrafish ovary.
3. Baker, S. (2021) (PhD). The Role and Regulation of Prostaglandins and their Receptors in Ovulation in the Zebrafish, Danio rerio.
4. Belanco, H. (2021) (PhD). Immune Response of the Purple Sea Urchin (Strongylocentrotus purpuratus) around the Perimetamorphic Period.
5. Cochrane, P. (2020) (PhD). Developmental plasticity and phenotypic flexibility in the oxygen sensing system of the amphibious fish Kryptolebias marmoratus.
6. Ding, Y. S. (2020) (MSc). The effects of thermal acclimation on cardiac cellular signalling pathways in rainbow trout (Oncorhynchus mykiss).
7. Goodwin, M. (2021) (PhD). Enrichment and variability of rearing environment influence brain size and behaviour of hatchery-reared wild brook charr (Salvelinus fontinalis).
8. Lau, E. P. (2020) (PhD). Pathways of Hydroxyurea Synthesis in the Mitochondria of the Little Skate (Leucoraja erincea).
9. Laura Austin (2020) (MSc) Neurogenesis following brain injury in the leopard gecko (Eublepharis macularius).
10. Lavery, J. M. (2022) (PhD). Investigating the effects of highly preferred environmental enrichment on the behaviour and welfare of laboratory zebrafish (Danio rerio).
11. Liu, Y. F. (2021) (PhD). Comparative Neuromorphology and Electrophysiology of Purkinje Cells in the Leopard Gecko, Mouse, and Chicken.
12. Luck, K. (2020) (PhD) The effects of multiple stressors on the ecophysiology of Lampsilis siliquoidea: Effects and interactions among water temperature, velocity and suspended solid concentration.
13. Matiyo Ojehomon (2020) (MSc) Insertional vs Targeted Mutagenesis in the Development of Zebrafish as an In Vivo Model for Cardiomyopathy.
14. Moran, N. (2021) (PhD). An Investigation into the Potential Use of 6-Gingerol to Combat Endotoxemia and Reduce Inflammation during Tissue Trauma in Larval Zebrafish.
15. Rossi, G. (2021) (PhD). Skeletal muscle remodeling in amphibious fishes out of water.
16. Sanford, R. (2022) (PhD) Identifying sub-lethal endpoints of stress in ramshorn snail (Planorbella pilsbryi) using non-targeted metabolomics on hemolymph.
17. Tunnah, L. (2022) (PhD). Surviving in Extreme Environments: Adaptive, Behavioural, and Plastic Responses of Amphibious Killifishes.
18. Wynen, H. (2021) (PhD). Thyroid Hormones Induce Programmed Cell Death in Sea Urchin (Stronglyocentrotus purpuratus) Larval Arms Prior to Metamorphosis.

2015-2019

19. Abiran Sritharan (2017) (MSc) Peroxisome proliferator-activated receptors (PPARs), phthalates and reproduction in the female zebrafish (Danio rerio).
20. Adrian Di Natale (2015) (MSc) Apolipoproteins in Rainbow Trout and Walleye.
21. Andrew Liorti (2015) (MSc) The Interactive Effects of Copper and Calcium on Calcium Uptake and Survivorship in Daphnia pulex.
22. Andrew Turko (2018) (PhD) Coping with Life on Land: Physiological, Biochemical, and Structural Mechanisms to Enhance Function in Amphibious Fishes.
23. Cory Schilling (2015) (MSc) Mechanisms of Reproductive Inhibition in Zebrafish (Danio rerio) Exposed to Ethinylestradiol, Nitrate and Ammonia.
24. Courtney McDermid (2016) (MSc) Progesterone as an endocrine disrupting chemical (EDC): Reproductive effects of waterborne progesterone on female zebrafish (Danio rerio).
25. Daniel Pasula (2016) (MSc) Investigating the Role of Axin2 in the Regulation of the Wnt Signaling Pathway in Early Zebrafish Development. Ehab Misk (2016) (PhD) Pathogenesis and Distribution of Spring Viremia of Carp Virus (SVCV) in Ontario.
26. Elias Taylor (2017) (MSc) Thyroid Hormones Accelerate Larval Skeletogenesis in Sea Urchins (Strongylocentrotus purpuratus) Through a Membrane Receptor-Mediated MAPK Signalling Cascade.
27. Elizabeth Johnston (2019) (PhD) Molecular Regulation of Collagen Deposition in the Extracellular Matrix of Cultured Ventricular Fibroblasts From Rainbow Trout, Oncorhynchus mykiss.
28. Emelia Myles-Gonzalez (2016) (MSc) The role of behavioural variation in trapping migratory Sea Lamprey.
29. Haider Khan (2019) (MSc) Investigation of the role of Naked 1 in Wnt Signaling.
30. Hailey Hunter (2018) (MSc) Tumor Necrosis Factor alpha and Ovulation in the Zebrafish (Danio rerio).
31. Jaramar Balmori-Cedeno (2017) (MSc) Autophagy-related gene expression in rainbow trout (Oncorhynchus mykiss) and their role in nutrient restriction in vivo and in vitro.
32. Joe Fiorino (2016) (MSc) Local Differentiation in the Defensive Morphology of an Invasive Zooplankton Species is not Genetically Based.
33. Joseph Anthony Kess (2017) (PhD) Genomic architecture of parallel ecological divergence in Galician Littorina saxatilis ecotypes.
34. Juan-Ting Liu (2019) (PhD) Autophagy and resistance to VHSV IVb in RTgill-W1 and Flavobacterium psychrophilum in rainbow trout (Oncorhynchus mykiss).
35. Karalea Cantera (2019) (MSc) The Influence of Genetic Effects and Plastic Responses on Brain Size and Behaviour of Polymorphic Brook Charr (Salvelinus fontinalis).
36. Katherine Tran (2017) (MSc) Selective Feeding of Freshwater mussels: Implications for Resource Partitioning.

37. Kathy Jacyniak (2016) (MSc) Cardiomyocyte proliferation in the lizard heart: exploring the criteria for spontaneous self-repair.
38. Keegan Lutek (2016) (MSc) The distribution and function of sea urchin histamine receptor 1 in larval Strongylocentrotus purpuratus.
39. Kelly Levesque (2016) (MSc) Effect of temperature on the hypoxia response of embryonic zebrafish, Danio rerio.
40. Laura Austin (2020) (MSc) Neurogenesis following brain injury in the leopard gecko (Eublepharis macularius).
41. Lauren Gatrell (2017) (MSc) The role of Glycerol in supporting Energy Production in the Hagfish Heart during Anoxia Exposure.
42. Lauren Overdyke (2015) (MSc) Ecological and Genetic Factors in the Distribution and Abundance of Larval Lake Whitefish (Coregonus clupeaformis) at Douglas Point, Lake Huron.
43. Lisa Harris, (2016) (MSc) The Effect of Water Velocity on Carbon Isotope Fractionation of Aquatic Macrophytes.
44. Love Sandhu (2019) (MSc) Characterization of cardiac actin gene editing in zebrafish using CRISPR-Cas9 technology.
45. Mark Bernards (2018) (MSc) Zebrafish upregulate cortisol catabolism as a neuroprotective coping mechanism in response to waterborne cortisol exposure.
46. Matiyo Ojehomon (2020) (MSc) Insertional vs Targeted Mutagenesis in the Development of Zebrafish as an In Vivo Model for Cardiomyopathy.
47. Maureen Jarau (2018) (PhD) Virulence of Flavobacterium psychrophilum, Antimicrobial Treatment and Intestinal Microbiota of Rainbow Trout Oncorhynchus mykiss.
48. Micheal Alcorn (2019) (MSc) Regulation of the cortisol stress response during and after exposure to chronic and severe hypoxia in crucian carp (Carassius carassius) and goldfish (Carassius auratus).
49. Nick Jefferies (2015) (PhD) Genome Size Diversity and Evolution in the Crustacea.
50. Nicola Gallager (2015) (MSc) The Effect of Overtraining on Motivated Behavior in Fire-Bellied Toads.
51. Nicole Wajmer (2016) (MSc) Understanding Phenotypic and Genetic Variation in Behaviours Linked to Migration in Lake Superior Brook Trout.
52. Noeline Subramaniam (2016) (MSc) Growth factor expression in normal and wounded skin: an investigation of scar-free wound healing in the leopard gecko (Eublepharis macularius).
53. Paige Vroom (2016) (MSc) Regeneration in Corallimorpharia.
54. Quentin Heffel (2016) (MSc) Skin Permeability of the Amphibious Mangrove rivulus, Kryptolebias marmoratus, in Response to Emersion.
55. Rakesh Mistry (2015) (MSc) Suspension Feeding of Juvenile and Adult Freshwater Mussels (Bivalvia: Unionidae) Under Flowing Conditions.
56. Rebecca McDonald (2017) (MSc) Neural Stem/Progenitor Cells and Postnatal Neurogenesis in the Leopard Gecko Brain.

57. Samantha Shaw-McDonald (2019) (MSc) Population Responses to Harvest Selectivity are Modified by Temperature in an Experimental Population.
58. Sarah Boggett (2017) (MSc) The Body Design of Hagfishes (Eptatretus stoutii and Myxine glutinosa) Protects from Biting Predators.
59. Sarah Graetz (2019) (MSc) Deterministic risk assessment of firefighting water additives to aquatic and terrestrial ecosystems.
60. Sarah Schorno (2018) (PhD) Biogenesis of Hagfish Slime: Timing and Process of Slime Gland Refilling in Hagfishes (Eptatretus stoutii and Myxine glutinosa).
61. Sarah Vita Donato (2017) (MSc) A spatiotemporal characterization of neural/stem progenitor cells in the body spinal cord of the leopard gecko (Eublepharis macularius).
62. Shannon Ferraro (2016) (MSc) Rupture Mechanisms of Mucous Vesicles from the Slime of Pacific Hagfish (Eptatretus stoutii): Functional Properties of Mucin-like Glycoproteins.
63. Shayla Tuttle-Raycraft (2018) (PhD) The effect of suspended sediment on the suspension feeding and distribution of freshwater mussels (Bivalvia: Unionidae).
64. Stefanie Bradley (2018) (MSc) Mechanisms of compensation following tail loss in the leopard gecko.
65. Tegan Williams (2017) (PhD) Environmental Stressors and the Neuroendocrine Stress Response in Zebrafish: Consequences and Cytoprotective Mechanisms.
66. Tessa Blanchard (2017) (MSc) Respiratory plasticity in the amphibious fish, Kryptolebias marmoratus during emersion.
67. Thariq Mohammed (2018) (MASc) Application of Airlift Pumps in the Aquaponics Industry.
68. Trevor Partch (2017) (MSc) Characterization of the Ovarian Corticotropin-Releasing Factor System and its anti-steroidogenic effects in Zebrafish.
69. Victor Fung (2019) (MSc) Effects of Porewater Flow on Interstitial Algal Composition and Juvenile Unionid Mussel Feeding.

2010-2014

70. Adrienne McLean (2014) (MSc) Understanding behaviour to improve trapping success of invasive Sea Lamprey.
71. Andrew Turko (2011) (MSc) Integration of behavioural, physiological, and morphological phenotypes in the amphibious fish Kryptolebias marmoratus.
72. Angela Telfer (2011) (MSc) The Roles of the Main Olfactory and Vomeronasal Systems in Prey Detection by Two Terrestrial Salamanders.
73. Ashley E.M. Miller (2013) (PhD) Iodine Uptake in Larvae of the Purple Sea Urchin (Strogylocentrotus purpuratus Stimpson 1857): Evidence for Peroxide Dependent Diffusion of Iodine in an Animal.
74. Barry Neil Madison (2013) (PhD) The Stress Response and Endocrine Mechanisms of Growth in Salmonids.

75. Cayleih Robertson (2012) (MSc) Developmental Plasticity of the Cellular Hypoxia Response in Zebrafish, Danio rerio.
76. Christopher Ostrowski (2012) (MSc) In vivo bioluminescent imaging in fish and intraspecies typing of Yersinia ruckeri.
77. David Iain Fraser (2013) (MSc) Tissue specific accumulation of hydroxyurea in elasmobranchs.
78. David Irwin (2011) (MSc) The regulation and function of the ovarian-derived insulin-like growth factor system in zebrafish (Danio rerio).
79. Elinor Jane Hughes (2011) (PhD) The effect of sex ratio on male reproductive success in painted turtles, Chrysemys picta.
80. Hanna Peacock (2014) (MSc) The role of angiogenesis during appendage regeneration.
81. Ian Ryerse (2014) (MSc) The Effects of Foodborne Deoxynivalenol Exposure in Rainbow Trout (Oncorhynchus mykiss) Experimentally Infected with F. psychrophilum.
82. Jahdiel Isaac Larraguibel (2013) (MSc) Investigating the Role of Wnt in the Activation and Localization of Nkd1.
83. Jamie-Lee Giardini (2014) (MSc) Consequences of Calcium Deficiency on Embryogenesis in a Keystone Freshwater Crustacean: Daphnia magna.
84. Jan Edward Lim (2013) (MSc) Control of the Endocrine Stress Response in Goldfish (Carassius auratus).
85. Jessica Grice (2012) (MSc) Pathogenicity of viral hemorrhagic septicemia virus IVb in walleye (Sander vitreus).
86. Jordan Mitchell Klaiman (2013) (PhD) The Effects of Thermal Acclimation on the Functional Properties of the Trout Myocardium.
87. Julia Emily Herr (2012) (MSc) Mechanisms of Rupture of Mucin Vesicles from the Slime of Pacific Hagfish (Eptatretus stoutii): Roles of Inorganic Ions and Aquaporin Water Channels.
88. Julie Vanden Byllaardt (2011) (MSc) The Role of Hydrodynamic Habitat in the Feeding Ecology of Freshwater Mussels (Bivalvia: Unionidae).
89. Kristin Bianchini (2012) (MSc) The Ontogeny of Blood Oxygen Transport and the Hypoxia Response in Early Life Stages of the Rainbow Trout, Oncorhynchus mykiss.
90. Kristina Mikloska (2014) (MSc) Effects of Hypoxia Exposure on Neurogenesis and the Hypothalamic-Pituitary-Interrenal (HPI) Axis in Larval Zebrafish (Danio rerio).
91. Lauren Jarvis (2014) (MSc) Early Warning Signals Detect Catastrophic Impacts of Experimental Warming.
92. Lowia Al-Hussinee (2011) (PhD) Pathogenesis of Viral Hemorrhagic Septicemia Virus (VHSV IVb) in Great Lakes Fish.
93. Madelyne Cosme (2014) (MSc) Inhibition of spawning in zebrafish (Danio rerio): Adverse outcome pathways of quinacrine and ethinylestradiol.

94. Mary Alexandra Reid (2012) (PhD) Plasma Pattern Recognition Receptors of Walleye (Sander vitreus M.) with an Emphasis on Mannose-binding Lectin-Like Protein and Viral Hemorrhagic Septicemia Virus.
95. Maude E.M. Tremblay (2012) (MSc) An effect of the invasive Round Goby (Neogobius melanostomus) on the recruitment of unionid mussel Species at Risk (Bivalvia: Unionidae).
96. Meghan Fuzzen (2010) (MSc) Regulation of the endocrine stress response and the modulating effects of sex steroids in zebrafish (Danio rerio).
97. Micheal Wells (2014) (MSc) Terrestrial Deposition of Embryos as a Strategy to Reduce Predation and Enhance Development in the Mangrove Rivulus, Kryptolebias marmoratus.
98. Nicholas C. Melnyk (2011) (MSc) Regulation of prostaglandin synthesis in the zebrafish ovary.
99. Olivia M. Knight (2014) (MSc) Characterizing the Role of Eicosanoids in Maturation-Inducing Steroid-Mediated Ovulation and Spawning in the Zebrafish (Danio rerio).
100. Sarah Kathryn Glover (2013) (MSc) The role of hydrodynamics in determining the habitat selection of juvenile unionid mussels.
101. Steve Dong Cho (2012) (MSc) Effects of environmental contaminants on the stress response of rainbow trout (Onchorhynchus mykiss) and brown bullhead (Ameiurus nebulosus).
102. Timothy McEwen Winegard (2012) (MSc) Slime Gland Cytology and Mechanisms of Slime Thread Production in the Atlantic Hagfish (Myxine glutinosa).

2005-2009

103. Angela Eykelbosh (2006) (MSc) The Regulation of Apoptosis in Serum-Starved Zebrafish Follicles: Involvement of Signal Transduction Pathways, Survival Factors and Cathepsin B.
104. Christine Regan (2005) (MSc) Regulation and expression of androgen receptor mRNA in Rainbow Trout at different sStages of spermatogenesis.
105. Chung-Wei Tan (2005) (MSc) Towards a DNA vaccine against Salmonid cryptobiosis.
106. Corinne Babchishin (2006) (MSc) The Regulation of Glutamine Synthetase in Rainbow Trout, Oncorhynchus mykiss.
107. Cosima Ciuhandu (2006) (MSc) The influence of hypoxia on the early life stages of the rainbow trout (Oncorhynchus mykiss).
108. Derek Alsop (2005) (PhD) Retinoid Biology and Toxicology in Fish and Frogs.
109. Jason Bystriansky (2005) (PhD) Regulation of Gill Na+, K+ -ATPase During Salinity Acclimation of Salmonid Fishes.
110. Jennifer Ings (2006) (MSc) Steroidogenesis in the Zebrafish Ovary: Basic Physiology and Application to Endocrine Disruption.
111. Kathryn Peiman (2005) (MSc) The causes and consequences of heterospecific aggression in Brook Stickleback (Culaea inconstans).

112. Marcie Ninness (2005) (MSc) The physiology of hatching in rainbow trout (Oncorhynchus mykiss) embryos.
113. Nathalie Newby (2006) (MSc) Investigation of the Pharmacokinetics and Effects of Morphine in Fish.
114. Raymond Mathew McCarthy (2006) (MSc) Competition mediated temperature selection in the intertidal crabs Pachygrapsus crassipes and Hemigrapsus nudus.
115. Sara Tavakoli (2006) (MSc) The Effects of Cortisol on Feed Intake and on the Expression of Appetite-Regulating Neuropeptides in Rainbow Trout (Oncorhynchus mykiss).
116. Shannon Costigan (2005) (MSc) The effect of thermal acclimation on aspects of cholesterol metabolism in the liver and gill of the Rainbow Trout (Oncorhynchus mykiss).
117. Tamara Rodela (2005) (MSc) Characterization and regulation of diurnal urea excretion in the Mangrove Killifish, Rivulus marmoratus.

2000-2004

118. Adrian Chin (2004) (MSc) Susceptibility and immune response of Salmo salar to the hemoflagellate, Cryptobia salmositica.
119. Amanda Karch (2004) (MSc) Behavioural and metabolic aspects of recovery from intense exercise in juvenile rainbow trout, Oncorhynchus mykiss.
120. Andrea Lister (2001) (MSc) Regulation of testosterone production by cytokines in the goldfish.
121. Andrew Muir (2004) (MSc) Age estimations of lake whitefish (Coregonus clupeaformis) in Lake Huron: Reducing the uncertainty.
122. Andrzej Januszkiewicz (2004) (MSc) Variation in predator-induced plastic responses and its consequences in polymorphic pumpkinseed sunfish (Lepomis gibbosus).
123. Anthony W. Wood (2002) (PhD) Apoptosis, atresia and ovarian development: a piscine perspective.
124. Bernadette Andrelli (2000) (PhD) A chemotherapeutic strategy against salmonid cryptobiosis.
125. Bryan Cassone (2004) (MSc) Genetic structure and phylogeography of Pachygrapsus crassipes along the north eastern and western Pacific coasts.
126. Christopher Jastrebski (2001) (MSc) Divergence and selection in trophically polymorphic pumpkinseed sunfish (Lepomis gibbosus).
127. Colin T.R. Darling (2002) (MSc) Lead shot contamination in soils and lead bioaccumulation in earthworms.
128. Daelyn Adele Woolnough (2002) (MSc) Life history of endangered freshwater mussels of the Sydenham River, southwestern Ontario, Canada.
129. Deborah Pakes (2002) (MSc) Changes in the strength of selection exerted on prey during the ontogeny of an experimentally introduced predator.

130. Elinor J. Hughes (2003) (MSc) Nest-site Selection, Hatching Success and Hatchling Over-Winter Success in Painted Turtles (Chrysemys picta).
131. Glenn Fines (2000) (MSc) The mechanisms of urea retention in the branchial epithelium of elasmobranches.
132. Guy Perry (2001) (PhD) The genetic architecture of thermal tolerance and correlated growth-related traits in rainbow trout, Oncorhynchus mykiss.
133. Ildiko Somorjai (2001) (MSc) Quantitative trait loci for fitness traits in Arctic charr: conservation in rainbow trout and correlations among traits.
134. Jaime Lynne Currie (2004) (MSc) The effects of cryptobiosis on reproduction in rainbow trout.
135. Kathryn A. Calp (2002) (MSc) Regulation of steroidogenesis in the goldfish ovary by activin and transpormin growth factor-beta.
136. Kenneth Oakes (2004) (PhD) Oxidative stress and bioindicators of reproductive function in fish exposed to pulp and paper mill effluents.
137. Kevin Jeffrey Parsons (2002) (MSc) Morphological plasticity as a factor in the evolution of trophically polymorphic pumpkinseed sunfish (Lempomis gibbosus).
138. Marcus Freeman (2000) (MSc) Design, development and testing of a system to measure sarcomere length by laser diffreaction in working muscle in vitro.
139. Marie Clement (2003) (PhD) The Feasibility of the Restoration of Atlantic Salmon (Salmo salar) into the Lake Ontario Basin.
140. Melissa Cameron (2004) (MSc) Evolutionary significance of embryonic diapause in turtles.
141. Melissa Evanson (2000) (MSc) Effects of selected polycyclic aromatic hydrocarbons on testosterone production in goldfish and rainbow trout.
142. Mellissa Grey (2001) (MSc) Predator-prey relationships of naticid gastropods and their bivalve prey.
143. Natasha Frick (2000) (MSc) Nitrogen metabolism and excretion in the mangrove killifish, Rivulus marmoratus.
144. Paul Craig (2004) (MSc) The effects of seawater transfer on the corticotropin-releasing factor system in rainbow trout (Oncorhynchus mykiss).
145. Phyllis Ann Essex-Fraser (2002) (MSc) Expression of glutamine synthetase in early life stages of rainbow trout (Oncorhynchus mykiss).
146. Rachael Woram (2001) (MSc) Construction of a genetic linkage map for Arctic charr (Salvelinus alpinus) and comparative mapping with Atlantic salmon, brown trout and rainbow trout.
147. Robin L. Morgan (2002) (MSc) Urea retention mechanisms in a marine elasmobranch, the little skate, Raja erinacea.
148. Sara L. Ashpole (2003) (MSc) Contaminant Levels and Embryonic Development on the Snapping Turtle (Chelydra s. serpentina) from Selected Great Lakes Areas of Concern.
149. Seanna McTaggart (2000) (MSc) Good genes or sexy sons? Testing the benefits of female mate choice in the painted turtle, Chrysemys picta.

150. Shelby L. Steele (2003) (MSc) Ontogeny of Osmoregulation in the Little Skate, Raja erinacea.
151. Suzanne Gray (2001) (MSc) Ecological character displacement in brook sticklebacks (Culaea inconstans).
152. Tricia Lundrigan (2001) (MSc) Genetic variation in cultured and natural populations of Arctic charr (Salvelinus alpinus) from North America.
153. Vcki L. Marlett (2003) (MSc) Evaluating in vitro Methods to Assess Xenoestrogens in Fish.

1998-1999

154. Arash Shahsavarani (1999) (MSc) Effects of temperature on embryonic physiology of arctic charr.
155. Carol Anne Pilley (1999) (MSc) Effects of temperature on the final stages of reproduction in male and female rainbow trout.
156. Glenn Wagner (1999) (MSc) Investigation of fish surgical techniques.
157. Istvan Imre (1999) (MSc) Developmental response of young-of-the-year brook charr (Salvelinus fontinalis) to water velocity.
158. Janet Lochead (1998) (MSc) The effect of body size, kinship, prior residency and food availability on aggression and contest outcomes on hatchling snapping turtles, Chelydra serpentine.
159. Kelly Wells (1999) (MSc) Characterization of androgen receptors in goldfish and rainbow trout.
160. Kristen Moore (1999) (MSc) Effects of temperature on the final stages of reproduction in male and female rainbow trout.
161. Louis Tremblay (1998) (PhD) The use of in vitro and in vivo assays to characterize the effects of estrogenic compounds in the rainbow trout (Oncorhynchus mykiss).
162. Nicole Koper (1998) (MSc) Ecological constraints on growth of painted turtles (Chrysemys picta) in northern climates.
163. Nikos Hontzeas (1999) (MSc) Strategies against cryptobiosis: the production of a recombinant protein for therapeutic purposes.
164. Terry Chadwick (1998) (MSc) Nitrogen excretion and expression of urea cycle enzymes during early life stages of Atlantic cod and rainbow trout.

APPENDIX 4- ALUMNI DESTINATIONS

Name (highest degree attained)	*Role, Institution/Company*	*Location*
Abiran Sritheran (MSc)	Laboratory Technician, Animal Health Laboratory, University of Guelph	Guelph, Ontario, Canada
Alexia Abbruzzese (BSc)	Laboratory Fisheries Technician, Ontario Commercial Fisheries Association	Wheatley, Ontario, Canada
Andrea Lister (PhD)	Research Coordinator at Wilfrid Laurier University	Waterloo, Ontario, Canada
Andrew Robertson (MD)	Family Medicine, Queens Family Health Team	Belleville, Ontario, Canada
Andy Turko (PhD)	PDF comparative and evolutionary physiology at Wilfrid Laurier University	Waterloo, Ontario, Canada
Angela Eykelbosh (PhD)	Environmental Health & Knowledge Translation Scientist, NCCEH	Vancouver, British Columbia, Canada
Angela Telfer (MSc)	Data Management Lead, Centre for Biodiversity Genomics	Guelph, Ontario, Canada
Anne Todgham (PhD)	Professor and Chair, Department of Animal Science, UC Davis	Davis, California, USA
Anthony Merante (MSc)	Plastics Campaigner at Oceana	Toronto, Ontario, Canada
Antony Wood (PhD)	Senior Director, Product Design & Strategy, Cell Signaling Technology, Inc.	Danvers, Massachusetts, USA
Arienna Balbar (PhD)	Co-Founder of Scient Analytics Inc.	Halifax, Nova Scotia, Canada
Ashley Bellin (DVM)	VCA Canada Rosedale Animal Hospital	Toronto, Canada Area
Ashley E Miller (PhD)	Science Communicator | STEAM Educator | Storyteller	Halifax, Nova Scotia, Canada
Barry Madison (PhD)	Assistant Professor in the Department of Biology, Brandon University	Brandon, Manitoba, Canada
Ben Speers-Roesch (PhD)	Assistant Professor in Biological Sciences, University of New Brunswick	St. John, New Brunswick, Canada
Bianca Cisternino (MSc)	Bycatch Coordinator at the Whale and Dolphin Conservation	Lytham St. Anne's, United Kingdom
Caleb Axelrod (PhD)	PDF at Washington University in St. Louis	St. Louis, Missouri, USA
Calli Freedman (DVM)	Veterinarian	Kamloops, British Columbia, Canada
Caley Nadon(DDS)	Dentist	Toronto, Ontario, Canada
Carolos Soares (PhD)	Researcher, Federal University of Santa Catarina	Florianopolis, Brazil
Cayleih Robertson (PhD)	PDF at McMaster University	Hamilton, Ontario, Canada
Christina Callegari (MSc)	Sustainable Seafood Coordinator at Ecology Action Centre	Halifax, Nova Scotia, Canada
Christina Simpson (MSc)	Manager, Opioid Response Team, Health Canada	Ottawa, Ontario, Canada
Christine Drader (BSc MFB)	First Nations Conservation Technician at Toronto Zoo	Toronto, Ontario, Canada
Christine Regan (MSc)	Research Technician, Environment Canada	Burlington, Ontario, Canada
Christopher Jastrebski (MSc)	Biologist/Lead Consultant at Ecological Logistics and Research Ltd.	Whitehorse, Yukon, Canada
Connor Reeve (MSc)	Doctoral Student at Carleton University	Ottawa, Ontario, Canada

Name (highest degree attained)	*Role, Institution/Company*	*Location*
Cory Schilling (PhD)	Independent Agribusiness Consultant, Researcher, Plant Breeder	Ontario, Canada
Crystal Lloyd (BSc)	Senior Biologist at Fisheries and Oceans Canada	Vancouver, British Columbia, Canada
David Fraser (MSc)	Lead Aquarist, Ripley's Aquarium	Toronto, Ontario, Canada
Daniel Kuefler (PhD)	Ecologist / Environmental Specialist	Charlotte, North Carolina, USA
Daniel Lingwood (PhD)	Assistant Professor in Medicine at Harvard Medical School	Cambridge, Massachusetts, USA
Derek Alsop (PhD)	Research Associate at McMaster University	Hamilton, Ontario, Canada
Douglas Fudge (PhD)	Professor, Chapman University	Orange, California, USA
Ehab Misk (PhD)	Research Scientist, Huntsman Marine Science Centre	St. Andrews, New Brunswick, Canada
Elinor Hughes (PhD)	Biology Instructor, Douglas College	Coquitlam, British Columbia, Canada
Elizabeth Johnston (PhD)	Scientific Writer – Patents Rapid Novar	Kitchener, Ontario, Canada
Elizabeth Sears (MSc)	Molecular Biology Research Technician at Agriculture and Agri-Food Canada	Ottawa, Ontario, Canada
Emily Merry (MSc)	Student Veterinarian, Ontario Veterinary College	Guelph, Ontario, Canada
Foster Scott (DVM)	Veterinarian, Veterinary Aquatic Solutions	Ontario, Canada
Frances Stewart (PhD)	Professor and Canada Research Chair in Northern Wildlife Biology at WLU	Waterloo, Ontario, Canada
Georgina Cox (PhD)	Assistant Professor, Washington State University	Pullman, Washington, USA
Gustavo Betini (PhD)	Data Analyst, Mental Health Research Canada	Waterloo, Ontario, Canada
Guy Perry (PhD)	Program Lead, AquaBounty Canada	Souris, Prince Edward Island, Canada
Hailey Hunter (MSc)	Laboratory Technician at Western University	London, Ontario, Canada
Hanna Peacock (PhD)	Belgian Cancer Registry Data Analyst	Haacht, Flemish Region, Belgium
Ian Ryerse (DVM)	Veterinarian, Allendale Veterinary Hospital	Barrie, Ontario, Canada
Ildiko Somorjai (PhD)	Senior Lecturer, University of St. Andrews	St. Andrews, Scotland, United Kingdom
Jackie Pallarca (BSc)	Veterinary Technician Student, Seneca College	Toronto, Ontario, Canada
Jacob Maxwell (BSc)	Student Veterinarian, Ontario Veterinary College	Guelph, Ontario, Canada
Jan Edward Lim (MSc)	Community Operations, Market Specialist, Facebook	Ontario, Canada
Jaramar Anna Balmori (MSc)	Food Processing Specialist Inspector, Canadian Food Inspection Agency	Ottawa, Ontario, Canada
Jason Bystriansky (PhD)	Associate Professor, DePaul University	Chicago, Illinois, USA
Jeff Stuart	Professor, Brock University	St. Catherines, Ontario, Canada
Jennifer Ings (PhD)	Senior Aquatic Scientist at Minnow Environmental Inc.	Burlington, Ontario, Canada
Jesse Holla (BSc MFB)	Fisheries Biologist at Environmental Resources Management	Vancouver, British Columbia, Canada
Jordan Klaiman (PhD)	Project Manager, Heart Regeneration Program, University of Washington	Seattle, Washington, USA
Joseph Salerno (MSc)	Technologist at Environment and Climate Change Canada	Burlington, Ontario, Canada

Name (highest degree attained)	Role, Institution/Company	Location
Julie Trus (BSc)	Ecology professional	Canada
Julie Vanden Byllaardt (MSc)	Assistant Coordinator, Conservation Halton	Hamilton, Ontario, Canada
Kara Layton (MSc)	Lecturer in Marine Biology at University of Aberdeen	Aberdeen, Scotland, United Kingdom
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Name (highest degree attained)	*Role, Institution/Company*	*Location*
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Michelle Lavery (PhD)	Farm Animal Welfare Program Associate at Open Philanthropy	San Francisco, California, USA
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Name (highest degree attained)	Role, Institution/Company	Location
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