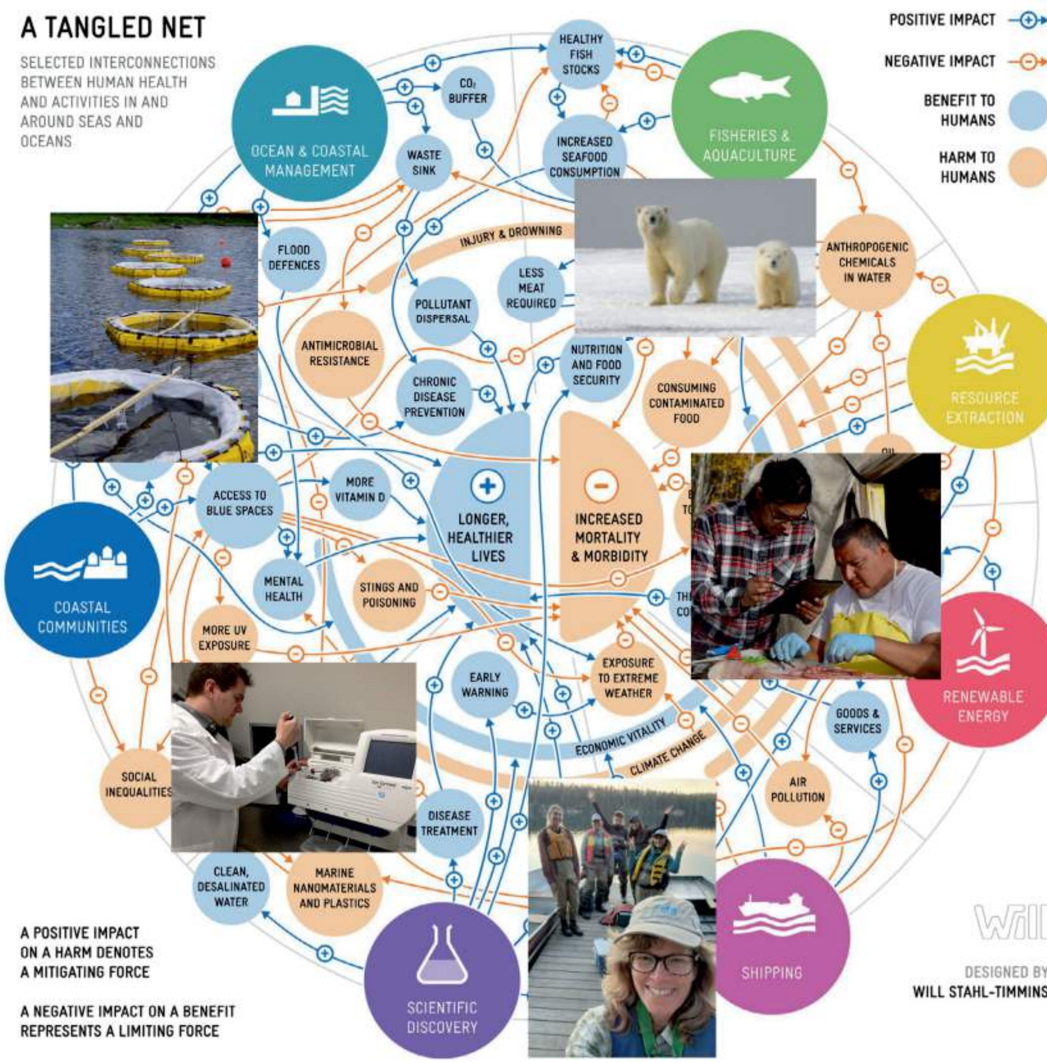
Canadian Ecotoxicity Workshop (CEW): Fifty Years 1974 – 2024

A history of ecotoxicology in Canada and future directions



CANADIAN ECOTOXICITY WORKSHOP

Edited by:
Gordon R. Craig
Rick Scrogggins

Canadian Ecotoxicity Workshop (CEW): Fifty Years 1974 – 2024

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2025

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Dedication

Dedicated to the environmental research scientists, managers, students and staff from all sectors of our society who over the last half century have worked to make Canada a safer, cleaner more eco-friendly world in which to live.

Fifty Years of CEW

Acknowledgments

The editors recognize the CEW Board of Directors, particularly the past president Carrie Rickwood and current president Ryan Prosser for their support and encouragement of this project. The organizing committee of the 50th meeting in Kitchener-Waterloo initiated the anniversary plenary and Jim McGeer was instrumental in coordinating our scheduling of the plenary session.

The contributing authors were generous in preparing their respective plenary presentations and preparing the following chapters contained in this history of ecotoxicology.

The Advisory Committee to the Board representing the principal sectors of the CEW membership has been instrumental in the transition from ATW to CEW and guiding the Board and Organizing Committees in new directions. However, the workshop organizing committees themselves are what makes CEW sustainable and continue to thrive. Their OG members from past meetings are listed in Appendix I.

Of course, sponsors of each meeting have provided the financial security for annual meetings and the contingency fund. This sponsorship also supports students by reduced the meeting registration fee, funding for best presentation awards, travel grants, mentor events and more. Sponsor logos are presented in Chapter 3 and cover the last fifty years of meetings.

Dr. Peter Wells has been a constant champion and contributor to both editors and of our respective causes and interests in recording the history of CEW. Peter’s enthusiasm and consistent optimism has been contagious and inspiring.

Acronyms

2,4,5-T	2,4,5-trichlorophenoxyacetic Acid
3Rs	Replacement Reduction Refinement
ANOVA	Analysis of Variance
AOP	Adverse Outcome Pathway
ASTM	American Society for Testing and Materials
ATW	Aquatic Toxicity Workshop
APHA	American Public Health Association
CCME	Canadian Council of Ministers of the Environment
DFO	Department of Fisheries and Oceans
EC	Environment Canada
EEM	Environmental Effects Monitoring
EPA	United States Environmental Protection Agency
EPS	Environmental Protection Service (Environment Canada)
IGATG	Inter-Governmental Aquatic Toxicity Group
IGETG	Inter-Governmental Aquatic Ecotoxicity Group
IJC	International Joint Commission
ISO	International Organization of Standardization
NAS	National Academy of Sciences
OECD	Organization for Economic Co-operation and Development
OMOE	Ontario Ministry of Environment
OMOEE	Ontario Ministry of Environment and Energy
OWRC	Ontario Water Resources Commission
SETAC	Society of Environmental Toxicology and Chemistry
SOP	Standard Operating Procedure
CABIN	CanadianAquatic Biomonitoring Network
CALA	Canadian Association for Laboratory Accreditation
CBM	Community-based Monitoring
CEC	Chemicals of Emerging Concern
CEPA	Canadian Environmental protection Act
DDT	Dichloro-diphenol-trichloroethane
DEI	Diversity Equity and Inclusive
QA/QC	Quality Assurance/Quality Control
DEI	Diversity Equity and Inclusive
DNA	Deoxyribonucleic Acid
ECCC	Environment and Climate Change Canada

EDA	Effect-directed Analysis
EE2	17a-ethynylestradiol
EIA	Environmental Impact Assessment
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
HOTO	Health of the Oceans
IISD-ELA	International Institute for Sustainable Development - Experimental Lakes Area
LC-HR-MS/MS	Liquid Chromatography High-resolution Tandem Mass Spectrometry
MARTOX	Marine Ecotoxicology
MoA	Mode of Action
NGO	Non-governmental Organization
NGS	Next-generation Sequencing
OHH	Ocean and Human Health
OHI	Ocean Health Index
PAH	Polyaromatic Hydrocarbons
PAPER	Pulp and Paper Effluent Regulation
PBT	Persistent Bioaccumulative and Toxic
PCR	Polymerase Chain Reaction
PFAS	Polyfluoroalkyl Substances
QA/QC	Quality Assurance/Quality Control
RNA	Ribonucleic Acid
TEK	Traditional Environmental Monitoring
TIE	Toxicity Identification Evaluation
UNCLOS	United Nations Convention on Law of the Sea
UNESCO	United Nations Educational Scientific and Cultural Organization

FOREWORD

The Canadian Ecotoxicity Workshop (CEW) meeting of 2024 held in Kitchener-Waterloo represented the 50th year since the first meeting in Winnipeg in 1974. The organizing committee decided to begin the meeting with a plenary showcasing the progress of ecotoxicity over the last half century. A number of us, Kelly Munkittrick, Guy Gilron, Rick Scroggins and Gordon Craig offered to organize the event and invite presenters to cover a wide range of topics. This book springs from the 50th anniversary plenary session.

The objective was to divide each presentation into two parts; the first being a historical perspective on each topic and the second was to identify future developments or direction anticipated in the coming years. This was accomplished by inviting long established researchers and long time CEW supporters to co-present past and future perspectives. Each presenter team was then invited to convert their plenary presentation to a chapter that would form a significant portion of this 50th anniversary publication.

This project was also an opportunity to update the earlier publication “Forty Years of the Aquatic Toxicity Workshop 1974 – 2013” (Craig, 2014) to cover significant history from the past 10 years and make the 50th publication more inclusive and broader ranging. Chapters 2 and 3 focus on earlier history which has been updated to cover significant changes that lead to the current workshop scope and design. For example, the former Aquatic Toxicity Workshop (ATW) went through a corporate transition with a formal election and reporting format together with an expansion of topics, a name change, Canadian Ecotoxicity Workshop and a corporate logo to better reflect the increase in scientific scope.

The plenary session authors have been thorough in reviewing key topics from the early days of toxicity test development, chemical analysis, omics, environmental monitoring, biological community responses and field assessments to the integration of ocean health that will provide readers a sense of foundation in ecotoxicology. There is also a sense of how public perception responded to and guided environmental protection and conservation.

Collectively, we have covered a lot of ground and trust you will enjoy the history and perspectives on the future direction of our discipline.

The Editors – Gordon R. Craig and Rick Scroggins

Reference

Craig, G.R. 2014. Forty years of the Aquatic Toxicity Workshop 1974-2013. The Canadian National Aquatic Toxicity Workshop, Dartmouth, Nova Scotia, Canada p1-27 . In : P. Jackman, L.E. Burridge, M. Murdoch, R. Morais, J. Leblanc and R. Allen Jarvis (Editors). 2014. Proceedings of the 40th Annual Aquatic Toxicity Workshop: October 6-9, 2013, Moncton, New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 3098 xiv + 114 p
https://www.ecotoxcan.ca/_files/ugd/f18aa9_92bb2f88a1884e8ab2081327b8b535b2.pdf

CHAPTER 1

INTRODUCTION

Celebrating 50 Years of the Canadian Ecotoxicity Workshop

by Carrie J. Rickwood
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In 1974, a small but visionary group gathered for the first official Canadian meeting focused on ecotoxicity, to survey toxicity testing laboratories across the country and assess their capacity, methodologies, and the species used in testing. That inaugural meeting brought together 40 participants and featured 23 presentations—modest numbers by today's standards, but it laid the foundation for what would become the Canadian Ecotoxicity Workshop.

The topics discussed in those early years were focused on fundamental issues such as the development of testing methodologies, and the impacts of pulp mills, metals, and the oil industry. These themes captured the scientific challenges of the time and formed the building blocks of Canada's ecotoxicological research.

Two decades later, the landscape began to shift with the introduction of Environmental Effects Monitoring (EEM) and standardized sublethal toxicity tests for fish, invertebrates, vascular plants, and algae. During this period, the Aquatic Toxicity Workshop (ATW)—the precursor to CEW—evolved with national and global environmental priorities. By 1990, one of the most well-attended workshops was held in Vancouver, thanks in large part to Peter Chapman's outreach efforts, and attracted participants from both Canada and the United States.

Throughout the 1990s and early 2000s, collaborative efforts flourished. National working groups, including the Canadian Council of Ministers of the Environment (CCME) multi-media quality objectives group, the Inter-Governmental Ecotoxicological Testing Group (IGETG), and technical working groups for EEM and oil sands, aligned their efforts through CEW. Session topics

Figure 1: 50th Anniversary graphic prepared by FuseLight Crative Inc. based on plenary presentations at 2024 CEW meeting at Kitchener / Waterloo, Ontario.

continued to broaden to reflect emerging scientific and technological advancements—pharmaceuticals, aquaculture, bridging the gap between lab and field studies, endocrine disruption, and oil sands research.

By 2010, the Toronto CEW welcomed over 400 participants and featured 234 presentations—not to mention an unforgettable "Thriller" dance at the banquet. In 2015, CEW officially adopted its current name to reflect the expanding scope of research that now included soils and wildlife. By this time, CEW had also solidified its reputation as a student-focused meeting, with a well-established student program and enthusiastic community of mentors committed to supporting the next generation of Canadian ecotoxicologists.

As we reflect on the past, we must also take time to remember those we've lost along the way. Rick Playle, Peter Chapman, and Art Niimi were all steadfast supporters of CEW, particularly acting as mentors to student attendees and supporting the student program. Their legacies continue with the Playle Award for best thesis, Peter Chapman Outstanding Student Platform Award, and the Arthur J. Niimi Outstanding Student Poster Award.

Over 50 years, both science and society have changed, and likewise, CEW continues to evolve. Topics such as non-vertebrate alternatives, omics, selenium, microplastics, nanoplastics, and eDNA have taken center stage, underscoring the rapid pace of change in environmental science and toxicology. We also now recognize that impactful research cannot occur in isolation. Interdisciplinary collaboration, diverse perspectives, and holistic thinking are essential. CEW has provided, and will continue to provide, a space where Canada's unique environmental questions are examined through multiple lenses—academic, governmental, industrial, and Indigenous.

The CEW Board commissioned a live graphic recording to commemorate the 2024 50th plenary (Figure 1). It is a beautiful illustration of the evolving narrative of the Canadian Ecotoxicity Workshop over the past 50 years. Beginning in the 1960s with growing concerns over environmental impacts and the development of foundational regulations, the journey advances through decades marked by evolving scientific innovation. Key themes include the importance of collaborative efforts, empowering innovation, and connecting mechanistic understanding with real-world endpoints. The future vision highlights the urgency of addressing the threat of climate change and threats to habitat and ocean health, while also highlighting the need for collaboration, and the importance of linking globally to create impactful solutions. This graphical representation serves as both a tribute to past achievements and a roadmap for shaping a more integrated and effective future in ecotoxicology.

As we embrace technological advancements and new ways of communicating science—through social media, digital platforms, and beyond—we also face new challenges. Misinformation is on the rise, and the need for scientific integrity has never been more critical. CEW plays a vital role in addressing these issues, offering a venue for rigorous peer discussion, validation of findings, and strategizing how best to communicate our science to policymakers and the public.

At its core, CEW remains true to its roots: a collaborative, supportive community for Canadian ecotoxicologists. While we may not know what CEW will look like in another 50 years, we do know this: Canada's distinct geography, geology, and biology require tailored approaches to environmental science. From the beginning, CEW has been the place where these national needs are explored, debated, and advanced.

Ultimately, the future of CEW lies in your hands. This is your community. As we look ahead to the next 50 years, we encourage you to stay engaged, share your knowledge, challenge ideas, and support one another. Together, we will shape the next chapter in Canadian ecotoxicology.

CHAPTER 2

Inexhaustible Abundance to the need for Controls: How we got to ATW 1974

by Gordon R. Craig
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The history of the Canadian Ecotoxicity Workshop (CEW), previously known as the Aquatic Toxicity Workshop (ATW) has been the product of changing mindsets / needs / realities / priorities. Let's start with the mindset 200 years ago because it establishes the thinking up to 1950 when environmental protection and conservation was truly adopted by the general public.

The resources of Canada were fiscally recognized by King Charles II of England who granted a charter to the Company of Adventurers in 1670 and permitted their Hudson Bay Company rights to all the resources in the Hudson Bay watershed (Figure 1). It read:

The Company of Adventurers of England operating as the Hudson Bay Company, incorporated by Charles II is granted "….unto them and their Successors, the sole Trade and Commerce of all those Seas, Streights, Bays, Rivers, Lakes, Creeks, and Sounds, in whatsoever Latitude they shall be, that lie within the entrance of the …..Hudson's Streights" be they possessed or unpossessed by the Crown.

The Company is awarded fishing rights for "...Fishing of all Sorts of Fish, Whales, Sturgeons, and all other Royal Fishes, in the Seas, Bays, Inlets, and Rivers within the Premises, ...and all Mines Royal, as well discovered as not discovered, of Gold, Silver, Gems, and precious Stones, to be found or discovered within the Territories ...and that the said Land be from henceforth [be] called Rupert's Land". (Charles II, 1670).

Here was a world of inexhaustible resources set in a backdrop of unlimited assimilative capacity. The population of Canada was largely measured by the

Figure 1: The Hudson Bay Charter of 1670 signed by King Charles II of England.

Table 1: Creation of Government Agencies and Legislation
1952 - IJC Boundary Water Objectives
1956 – BC - Pollution Control Act – BC Pollution Control Board
1956 – ON - OWRC created
1963 – NS - Nova Scotia Water Authority – develop standards
1965 – MN -Environmental Quality Act
1966 – AB - Department Public Health – some water quality guidelines
1968 – NS - Nova Scotia Water Resources Commission
1970 - Canada Water Act – Dept Environment created
1970 – SK - Sask Water Resources Commission - Water Quality Criteria
1972 - Great Lakes Water Quality Agreement
1972 – ON - Ministry of Environment created
1973 – NB - Clean Environment Act
1973 – NS - Nova Scotia Environment created
1973 – PQ -Environmental Quality Act – water quality regulations
1976 – MN – EQA – guidelines and licenses
1977 – AB – Surface Water Quality Objectives
1987 – MN – Environment Act

meager presence of European settlers and explorers in the thousands during the early years. Estimates of native populations in that time were about two million (Haines and Steckel, 2000). For two centuries the impact of colonization and industrialization had little impact on the availability of natural resources. By 1850, as Canada was attracting more immigrants due to land grants and military pensions. The country was putting on a growth spurt that would shortly be followed by Confederation in 1867. Canada's exponential growth had begun.

The beginning of the twentieth century exhibited expanding growth of villages, towns and eventually cities and with that increase of population density. Waste management became an issue as the population grew and assimilative capacity was progressively absorbed and later overwhelmed. Untreated waste from industrial operations like abattoirs, tanning operations, lumber, paper and mining mills were inevitably discharged to rivers (IJC, 1950). Complaints of odours, discolouration, floating debris in waters downstream of towns and villages were common. Fishing became measurably affected in lakes and rivers near these operations and degraded in quality and abundance.

It was not unusual for drinking wells and pit privies in towns and villages to be located on the same residential property. Cities began collection and consolidation of sewage but the spread of epidemic typhoid, diphtheria, and polio was recurrent from 1910 to 1940 and disease was the first clear indication that waste needed management and treatment.

Overlapping this public heath crises was the onset of WWI (1914-1918) followed by the great depression (1929-1939) and WWII (1939-1945). The first half of the twentieth century was chaotic; plagued by disease, economic collapse and global hostilities. Societal focus was on survival and productivity but there was a growing recognition that environmental degradation was becoming a public health problem.

By the end of the first half of the twentieth century the progression of the war-time economy transformed into a surge of economic and manufacturing development. The emphasis was to increase peace time productivity, put returning soldiers into manufacturing jobs and watch the economy surge. Environmental protection and preservation was not a consideration in those halcyon days of recovery.

Table 2: Creation of US Fish Toxicity Labs
1948 - Cincinnati, Ohio, in 1948 by U.S. Public Health Service 1953 - Hammond Bay Biological Station, Millersburg, MI 1953 - US Fish and Wildlife Service Laboratory, Leetown, WV 1959 - Fish Control Laboratory at LaCrosse, Wisconsin 1959 1959 - Fish-Pesticide Laboratory at Denver, Colorado 1959 1962 - Newtown Fish Toxicology Station Newtown, Ohio. 1967 - NWQL lab , Duluth MN

Table 3: Creation of Canadian Fish Toxicity Labs prior to 1974
1908 – Pacific Biological Station – Nanaimo , BC 1944 - Central Fisheries Research Station of the Fisheries Research Board of Canada – Winnipeg 1962 - Bedford Institute of Oceanography, Halifax NS 1962 - Cultus Lake Salmon Research Laboratory - BC 1966 – Freshwater Institute – Winnipeg, MN 1967 - CCIW – Canadian Centre for Inland Waters, Burlington ON 1968 - Experimental Lakes Area 1969 - Huntsman Marine Research Stn St. Andrews 1970 - Pacific Environment Institute (PEI), Vancouver

A Bright Line

A classic event played out in Espanola, Ontario that reflected the priority of economic recovery over environmental protection (Brubaker, 1995). A pulp and paper mill in town had closed down during the depression and over the following 16 years the Spanish River recovered from historic pollution and became a tourist destination for fishers. There were fishing camps up and down this now pristine river.

But in 1946, just after the end of the great war, the Kalamazoo Vegetable Parchment Company bought the mill and resumed operations. There was no effluent treatment and the week after startup dead fish surfaced along the length of the river. Residents and lodge owners were furious and loaded the front steps of the mill office in town with piles of dead fish. They followed up by suing the mill for violation of their riparian rights in 1948 and the court served the mill an injunction to shut down that was up held in the Supreme Court. The mill protested to the Ontario government of Leslie Frost that in turn passed in 1950, an Act Respecting the KVP Company, to remove the injunction and allow the mill to operate to preserve the economy and retain jobs.

This 1950 clash among residents, the mill administration and the government reflected a clear message that protecting jobs and the economy superseded protection of environment and represents a bright line in history. Shortly thereafter in 1956, it was the same Premier Leslie Frost of Ontario who, with the encouragement of US President Eisenhower, created the Ontario Water Resources Commission (OWRC). The Commission was charged to build and operate drinking water supplies and sewage disposal works and protect the quality of water in the province (OME, 1969). Now the converse was the case; environmental protection superseded jobs and the economy.

Creation of Agencies, Legislation and Testing Labs

The 1950s, 1960s ,and 1970s saw an explosion of government agencies and legislation (Table 1). Water quality agencies, pollution control agencies, environmental departments were created, international agreements were established with the United States who shared the Great Lakes shoreline. Every province in the country created Environmental agencies. Environmental quality and protection became enshrined in laws and regulations after 1950.

Agencies needed to know “How Clean is Clean” and how to achieve that number. Canada was not alone in defining “Clean”. In fact activities in the

United States were a great influence in what was happening in Canada. Throughout the 1950s and 1960s the US Fish and Wildlife Service was developing fish toxicity laboratories (Table 2) to determine chemical concentrations that were safe for fish (U.S. EPA , 1988; Dryer et al. 2020). These values were then being incorporated into water quality criteria and regulations. Similar labs and research facilities were being built across Canada in the 1960 in Winnipeg, Nanaimo, Bedford, Cultus Lake, Burlington, St. Andrews, and Vancouver (Table 3).

Influential Personalities

There were other forces in play in the 1960s besides government initiatives. Young scientists were making their way into a post wartime economy where productivity was a priority and waste management was, if not out of sight, certainly out of mind.

Don Mount started his career working for US Fish and Wildlife and spent his early years investigating fish kills through the industrialized US. He remarked at the time that unrestrained pollution was “too thick to navigate and too thin to cultivate”. Don went on to lead research facilities in Newtown OH and Duluth MN and was a leader in the development of aquatic toxicity test methods and impact assessments (U.S. EPA , 1988; Dryer et al. 2020) that influenced Canadian policy development.

A young John Sprague, working out of Huntsman Marine station in NB, also spent his early days investigating fish kills due to spruce budworm spraying and mining operations. He became interested in toxicity testing and establishing reproducible protocols. He spent a year working in Corvallis with Peter Doudoroff who in 1960 wrote the first chapter describing fish and invertebrate toxicity test methods in Standard Methods (APHA, 1960). John followed up his work in Corvallis writing a trilogy in Water Research on toxicity test methods (Sprague 1969, 1970, 1971) that has formed the foundation of the standards we use today (see Chapter 4).

One of the most influential personalities in the early environmental movement was a middle aged lady working at US Fish and Wildlife as editor of publications. Rachel Carson also had a sideline of writing naturalist narratives about seascapes along the US eastern seaboard that became best sellers. One of her books won a National Book award. Later, a colleague from The New

Yorker suggested she investigate the rampant use of insecticides on America's landscape.

Rachel Carson published Silent Spring in 1962 (Carson, 1962) and it was a hit (Griswold, 2012). An easy to read narrative of the effects of insecticides on target and non-target organisms. DDT was a prime subject, which in its day was a wonder chemical, eliminating malaria, ridding agricultural pests, and was an effective de-louser of military personnel (see Chapter 7). It was equally deadly to pollinators and bio-magnified up the food chain to impair reproduction in top avian predators. Silent Spring was on the New York Times best selling list for 30 months.

Pesticide manufacturers tried to discredit her narrative work as "non-scientific"; they called her a "communist and spinster cat lady". Nonetheless, the US Congress invited her to give evidence of the harm of pesticides in the environment that led to regulatory controls.

By the 1970s a number of environmental NGOs were also created that further engaged and enraged public opinion for the need of environmental protections. Organizations like the Sierra Club, Green Peace, Pollution Probe formed with public support and protested government practice and lack of policy to protect the environment. Early Canadian environmental toxicologists were described in a

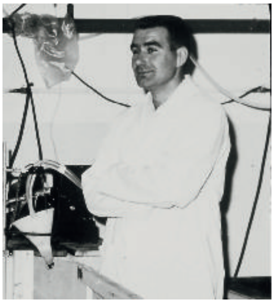
Rachel Carson (1907-1964) by Thomas Brosnihan - unedited - licensed under the Creative Commons Attribution-Share Alike 4.0 International

Craig

Don Alderdice

John Neal

John Sprague



Tom Beak

review by Sprague (1996) at the ATW meeting in St. Andrews, NB. The following are a few of the scientists who were conducting toxicity tests and studies across Canada before the establishment of ATW.

Don Alderdice conducted assessments on the effects of DDT spraying on salmon fry in the Maritimes through the early 1950s and then moved to the Nanaimo Biological Station in British Columbia. He reported on the response of salmon fry exposed to insecticides and pulp and paper effluents throughout the decade.

John Neal, working for the Ontario Department of Health in the early 1950s, focused on the issues involving the Kalamazoo Vegetable Parchment Company (KVP) in Espanola, where an old Abitibi Power and Paper mill was being reactivated after the war (see above).

John Sprague was one of the early workers to introduce the principles of pharmacology to the practice of aquatic toxicity testing in the mid-1950s while working on his PhD with the famous Fred Frye at the University of Toronto. After graduation, he worked at the St. Andrews Biological Station, where he studied pulp mill and mining effluent impacts on Maritime rivers as well as studies on DDT and its toxicity to salmon. He later became a professor at the University of Guelph.

Tom Beak arrived from Scotland in 1955 having resigned as the Assistant Inspector of Salmon Fisheries responsible for freshwater fisheries in Scotland and effects of water pollution on them (Langley, 2014). During that time he was responsible for writing the Salmon Fisheries Law. His first contract as a Water Pollution Consultant was with the Canadian International Paper Company in Port Hawkesbury on the Ottawa River. In 1955 he received $10,000 to conduct toxicity tests on the mill effluent and benthic surveys in the river thereby establishing the first environmental consulting company in Canada, Beak Consultants. Based on studies reporting the effect of pollution to insect larvae in English rivers and studies conducted in the Ruhr River in Germany, he created an index of benthic community health that became known as the Beak Index. As a result of the many personnel who flowed through Beak Consultants it became the mother of many subsequent consulting companies in Canada for next six decades.

Gérard Leduc conducted work with the Quebec Biological Bureau in the early 1960s and later taught at Sir George Williams University (now Concordia

Craig

Gérard Leduc

Terry Howard

James Servizi

University), supervising one of the early toxicity laboratories and focusing on the effects of cyanide and metalocynides on fish. Gérard was a Co-Chair of the 7th ATW in Montreal in 1980.

Perry Anderson, also from Sir George Williams University, conducted work in the mid- to late-1970s on metal speciation and the toxicity of metal mixtures to fish.

Terry Howard arrived from Britain and joined Don Alderdice at Nanaimo in the early 1960s, then moved on to B.C. Research to study the lethal and sublethal effects of pulp mill effluents on fish through the 1960s. B.C. Research was the pulp and paper industry's centre for process design, effluent treatment, and studies of environmental impacts from the 1960s to the 1980s.

James Servizi worked in the toxicity laboratory in Cultus Lake, B.C., for the International Pacific Salmon Commission from 1963 to 1993. It was his 1966 work (Servizi et al. 1966) that was used to derive the first pulp and paper effluent regulatory toxicity test, promulgated in 1971, of 80% rainbow trout survival in a 65% dilution of effluent over 96 hours of continuous flow exposure.

Aquatic toxicity testing methods had been very much dependent on individual researchers (Hunn, 1989) until the early publication of methods by ASTM (1954) followed by Douderoff's first Standard Methods chapter on toxicity test methods in 1960 (APHA, 1960). John Sprague published a series of three articles from 1969 to 1971 titled "Measurement of pollutant toxicity to fish" (Sprague 1969, 1970, 1971), the first of which was named a citation classic in 1979. He followed those in 1973 with the "ABCs" of pollutant bioassays (Sprague 1973). Charles Stephan published an acute toxicity test methods manual (EPA,1975); the product of a committee that had been meeting since 1971. Generic toxicity test methodology was well established but needed refinement to be reproducible, allow better understanding of the mechanisms of toxicity, and be adaptable to local and national requirements.

OECD Duluth Meeting

A separate meeting of ten Organisation for Economic Co-operation and Development (OECD) member countries was hosted by EC and the EPA in Duluth, Minnesota, in 1984 (Environmental Protection Agency and Environment Canada 1984). The goal of the meeting was to provide input for the 1985 OECD "Project on Guidance for the Use of Biological Tests in Decision Making for Water Pollution Assessment and Control". Subgroups were formed to address issues of (i) the application of testing approaches, (ii) use of biological tests in administrative decision making, and (iii) scientific considerations in designing a biological test system. The project was to provide guidance on the analysis and control of toxic effluents that are less costly and more environmentally effective than were approaches at the time.

The 1984 OECD meeting in Duluth published a number of important conclusions that reinforced not only the regulatory direction of Canada and the U.S. in the area of effluent toxicity testing, but that of Europe as well. Some conclusions included:

- Effluent toxicity tests provide valid, cost effective input to protecting the aquatic environment;
- Toxicity test data must be considered together with other chemical and hydraulic information;
- Toxicity tests can be used to establish long-term effluent quality and ambient quality trends;
- Maintaining and improving the skills of testing personnel is important;
- The reproducibility of toxicity tests is comparable to that of chemical tests;
- The use of a standard test species is more important than using resident species for testing;
- Whole effluent tests reflect the interactive effects of chemical components in effluents; and
- A tiered testing scheme should be used for the sake of economy.

Sergy Report and the IGAT Committee

While the OECD meeting affirmed an international recognition of the importance of biological testing, EC had already been well along the path of defining the role of ecotoxicological testing (MacGregor and Wells 1984). Two such parallel events were the formal creation of a Toxicity Technical Committee within EC–EPS in 1976 and an informal meeting of provincial and federal laboratory managers, which began about the same time or shortly after.

The Toxicity Technical Committee was internal to EC and initially chaired by Ed Pessah, out of the Dartmouth facility. It was formed to advise on technical matters related to effluent regulations and guidelines under the Fisheries Act. Trout toxicity test methods had already been published in effluent regulations and guidelines under the Fisheries Act for the pulp and paper (Environment

Canada 1971), petroleum (Environment Canada 1974), metal mining (Environment Canada 1975), textile (Environment Canada 1976) and alkali products (Environment Canada 1978) sectors. The test procedures at the time were not only technically problematic, being continuous flow, but could only be updated by revising the regulations or guidelines, which was administratively cumbersome. There was a need for a more flexible solution.

Concurrently, the managers of federal and provincial government aquatic toxicity laboratories in Dartmouth, Quebec City, Montreal, Toronto, Burlington/Hamilton, Winnipeg, Edmonton, and Vancouver began to meet independently because they were actually using the tests and were experiencing the difficulties first-hand. This group conducted trials to optimize loading rates in acutely lethal rainbow trout tests (Craig and Beggs, 1978) and later, evaluate the practicality of reference toxicants (Craig and Holtze 1981). In 1978, Art Beckett (EC, Edmonton) and Gordon Craig (then with the OMOE) decided to profile their meetings over the last several years and identify the work underway. They prepared a poster for the 1978 ATW in Hamilton and named the group Inter-Governmental Aquatic Toxicity Group (IGATG).

The interests within the informal IGATG and the formal EPS Toxicity Technical Committee converged as the membership overlapped but only federal laboratories participated in the EPS committee at that time. Initiatives in EC to establish a sound foundation for toxicity testing in industrial effluent regulations were introduced at the 1985 IGATG meeting and led to specific recommendations related to toxicity test procedures for management of EC–EPS (Sergy 1987). From 1985 to 1987, the IGATG committee became an important resource to the EC Laboratory Managers Committee, to the point where IGATG became the prevailing expert group since it included provincial toxicology laboratory managers and was often chaired by EC and provincial representatives over the years (Taylor et al., 2013).

The Alliston Workshop

A parallel activity to define the future for biological testing in Canada was the 1988 stakeholder workshop of industrial representatives, consulting firms, academics, and provincial and federal regulators hosted by EC in Alliston, Ontario. The proceedings of the Alliston workshop (Day et al. 1988) recommended a division of roles for EC (to prepare test protocols and QA/QC requirements), consulting firms (to conduct the regulatory testing) and industry (to report the testing results). The IGATG federal committee members sought funding from within EC–EPS programs shortly after the workshop to establish an external method writing contract, managed by Rick Scroggins of EC, to develop the first set of standard Reference and Generic test methods which established a viable means by which Canada could maintain sovereignty over its acute lethality test methods for regulatory compliance and monitoring requirements. Starting with the 1992 Pulp and Paper Effluent Regulations, the new rainbow trout and Daphnia magna Reference Methods could now be updated without changing regulations (i.e. "cited by reference" instead of incorporation of method in the regulation).

In 1991, EC created the Biological Methods Division (currently Biological Assessment and Standardization Section). As Chief of this division, Rick Scroggins was charged with continuing to develop standardized aquatic, sediment and soil toxicity test methods for application in federal and provincial regulations or permits. IGATG was already established and providing expertise for new method review and provided the perfect resource base support the EC biological test methods program. Throughout the next 35 years, Canadian standardized toxicological testing methods were published, including a number of tests measuring sublethal effects to fish, aquatic & soil invertebrates and aquatic & terrestrial plants (see Chapter 4).

Water Quality Criteria

Water quality criteria development relied on these early toxicity tests and there was a recognition that standard methods would become increasingly important. The European Inland Fisheries Advisory Commission of the Food and Agriculture Organization of the United Nations (FAO) was created and first met in 1960 with representatives from 14 European countries. In 1962 a working party headed by John S. Alabaster was created to develop water quality criteria for European freshwater fish (Holden, 1981). The first criteria addressed finely divided solids published in 1964 and reports on other contaminants were published through to the 1990s.

The United States passed the Water Quality Act in 1965, requiring individual states to develop water quality criteria, and the U.S. Environmental Protection Agency (EPA) began to take a lead with various compendium documents. The first U.S. water quality guidelines document appeared in 1972 (National Academy of Sciences 1972), the second in 1976 (Environmental Protection

Agency 1976). Ontario published its initial water quality criteria in 1967 and updated and expanded its policy between 1970 and 1994 (Ontario Water Resources Commission 1967, 1970; Ontario Ministry of the Environment 1978; Ontario Ministry of the Environment and Energy 1994). Environment Canada published its Guidelines for Surface Water Quality in 1979 (Environment Canada 1979a, 1979b) and continued water quality guideline development work through the Canadian Council of Ministers of the Environment (CCME), which was created in 1983 and continues today. All of these documents relied on reports and publications of metal or chemical toxicity to fish and invertebrates. The need for methods standardization increased as criteria expanded and regulatory monitoring expanded (see Chapter 4).

The combined activity of water criteria development, standardization of methods, the development of water quality regulations and the discussion between regulators and the regulated, provided the foundation for a national meeting of stakeholders.

The First Meetings

The first meeting of aquatic (environmental) toxicologists and environmental managers in Canada was hosted in 1973 by Tom Beak and BEAK Consultants in Toronto (BEAK, 1973). The pulp and paper regulatory toxicity test, a cumbersome continuous flow method, was in place and there was concern from industry as to where all of this was going. The meeting held in Rexdale, a suburb of Toronto, attracted 195 attendees from government, academia and industry. Among the six key presenters were John Cairns from Virginia Polytechnical Institute, John Sprague from the University of Guelph, and John Loch from the Fisheries and Marine Service (part of the Department of the Environment that later became DFO) in Winnipeg. Topics touched on methods, selection of test species, how best practicable treatment fit with regulations, and the need for effective communication between biologists and engineers.

The following year John Davis and John Loch of Canada Fisheries and Oceans at the Freshwater Institute in Winnipeg, decided to call together managers and researchers from Canadian laboratory operations (Table 4) to share their experience and discuss developments in environmental protection. That 1974 meeting attracted about 40 people and became recognized as the first ATW meeting. Test methods published in Standard Methods and ASTM were being used and modified in those labs to quantify fish and invertebrate toxicity in

Table 4: Canadian Toxicity Laboratories / Managers Operating by 1974
B.C. Research, Vancouver , B.C. (Terry Howard)
Beak Consultants, Toronto, (Fahmy Fahmy)
Bio Research Labs, Pointe Claire, P.Q.
Enviroclean Ltd. London, ON (Richard Bland)
EPS, Burlington (Victor Cairns)
EPS, Halifax (Ed Pessah, Peter Wells)
EVS Consultants (Gary Vigers / Peter Chapman)
Freshwater Institute – Fisheries and Oceans (John Loch, Lyle Lockhart)
Guelph University, Guelph ON (John Sprague)
Institute of Envir. Sc & Eng, U of T, (Tom Hutchinson)
Lakehead University (George Ozburn)
Noranda Research Centre , Pointe Claire (C. Delisle)
Ontario Ministry of Envir., Toronto ON (Gordon Craig)
Pacific Envir. Institute (Gayland Greer, John Davis)
Pacific Salmon Fisheries Commission, New Westminster , BC (James Servici)
Pollutech Pollution Adv. Services, Oakville, (David Casson)
Sir George Williams University, Montreal (Gerard Le Duc, Sylvia Ruby, G. Dixon, M. Spyer)

industrial effluents discharged to waterways. Across the country it was clear that untreated waste waters were impairing aquatic life. The 1970s ushered in Canada's federal effluent regulations, specifically, the inclusion of the 96-hour rainbow trout LC50 test in addition to chemical tests, to regulate effluent quality (see Chapter 4).

Industry was not happy. They had accepted chemical limits as reasonable and logical because that was how they managed the quality of their products. But a "fish test"? They claimed there were no dead fish in their rivers; what was the point? In fact, as EEM assessments downstream of pulp and paper mill discharges later discovered (see Chapter 8), sometimes there were also no live fish in the downstream near field zones of rivers and lakes. Industry has since come to embrace environmental protection with corporate policies. They meet acute lethality compliance requirements and regularly finance environmental assessments as a normal practice for the approval of operational expansion and incorporation of new technologies.

The success of the these initial meetings demonstrated that there was plenty of material to discuss among regulators, practitioners and researchers in government, academia and the consulting industry. The second meeting in 1975 attracted about 90 attendees and was hosted by Gordon Craig of the Ontario Ministry of Environment. He applied the name Aquatic Toxicity Workshop (ATW) to the meeting which was derived from the extended title of the first meeting and a consensus of discussion among the 1975 participants. The following year, 1976, Ed Pessah and Peter Wells of Environment Canada in Halifax hosted the meeting with the participation of 100. It was that third meeting that confirmed that ATW was gaining momentum; the topics were compelling and others across the country showed a willingness to host and sponsor subsequent meetings as the list of meeting chairs over the years shows in Appendix 1.

The tools of aquatic and terrestrial toxicology have, over the years, been standardized and refined to measure effects on exposed organisms at orders of magnitude lower concentrations than in the days of ten fish in a bucket. The progress has been astounding. Application of these tools has been embedded in large-scale environmental assessments applied to private industry and public sector across the country. The discipline of environmental toxicology has advanced so that sensitive population responses to long-term exposure of chemicals, possibly below levels of analytical detection, can now be determined (see Chapter 9). We now have a very good understanding of our capabilities and know many of the environmental contaminants that can impact biological systems (see Chapter 7). Our computational knowledge and capability now possibly exceeds our ability to measure and detect chemical effects within the milieu of natural ecological variability.

Most important among the development of our skills and knowledge has been establishing ownership over the environmental management tools used nationally. Canada developed its own water quality objectives, toxicity test methods, analytical procedures and environmental assessment techniques that can be refined and modified as national and local needs require. Consequently, Canada is no longer reliant on other countries (United States ASTM or EPA) or multi-national standards organizations like OECD or the International Organization for Standardization (ISO) for environmental toxicology assessment methods as it was decades ago. CEW has provided an important and functional forum to address national interests, policies and issues in the protection of ecosystems in a timely manner over the last 50 years.

References

APHA (American Public Health Association). 1960. Standard methods for the examination of water and wastewater, 11th edition. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. New York,

ASTM D1345-45T. 1954. Standard Test Methods for Evaluating Acute Toxicity of Water to Fresh-Water Fishes. Annual Book of Standards - Water, Amer. Soc. Testing Materials, Philadelphia, PA.

Beak, 1973. Beak toxicity seminar proceedings. Beak Consultants Ltd., Toronto, Canada.

Brubaker, E. 1995. In the name of the public good. Chapter 4 in Property rights in the defense of nature. Earthscan Publications Limited and Earthscan Canada

Canada Not-for-profit Corporations Act. 2011. Government of Canada, Ottawa, Canada

Carson, R. 1962. Silent Spring. Houghton Mifflin Company.

Charles II, 1670. The Royal Charter incorporating The Hudson’s Bay Company. Printed by Henry Kent Causton & Son, Nag’s Head Court, Gracechurch

Street. 1865.

Craig, G.R. 2014. Forty years of the Aquatic Toxicity Workshop. The Canadian National Aquatic Toxicity Workshop. Dartmouth, Nova Scotia, Canada.

Craig, G.R., and Beggs, G.L. 1979. Evaluation of fish loading rates in regulatory static bioassays. In Proceedings of the Fifth Annual Aquatic Toxicity Workshop, November 7-9, 1978, Hamilton, Ontario. Fish. Mar. Serv. Tech. Rep. 862, pp. 145-160.

Craig, G.R., and Holtze, K.E. 1981. Interlaboratory test comparison I: Ammonia toxicity. In Proceedings of the Seventh Annual Aquatic Toxicity Workshop: November 5-7, 1980, Montreal, Quebec. Can. Tech. Rep. Fish. Aquat. Sci., 990. pp. 338.

Day, K.E., Ongley, E.D., Scroggins, R.P., and Eisenhauer, H.R. (Editors). 1988. Biology in the new regulatory framework for aquatic protection: Proceedings of the Alliston workshop, April 26-28, 1988. Environment Canada, Burlington, Canada.

Dryer, J.N., Mount, D.L, Brungs, W.A., Horning, W.B., Neihcisel, T.W. .2020. History of Newtown Fish Toxicology. U.S. EPA . Washington. D.C.

Environment Canada. 1979b. Guidelines for surface water quality: Volume 2 – Organic chemical substances. Ottawa, Canada.

Environment Canada. 1979a. Guidelines for surface water quality: Volume 1 – Inorganic chemical substances. Ottawa, Canada.

Environmental Protection Agency. 1975. Methods for acute toxicity test with fish, macroinvertebrates, and amphibians. EPA/660/3-75/009. Washington, D.C., USA.

Environmental Protection Agency. 1976. Quality criteria for water [The Red Book]. EPA/440/9-76/023. Washington, D.C., USA.

Griswold, E. 2012. How “Silent Spring” ignited the environmental movement. The New York Times Magazine. New York, New York.

Haines, M.R., Steckel, R.H. 2000. A population history of North America. Cambridge University Press.

Holden, A.V., 1981. Historical review of EIFAC activities. EIFAC Occas.Pap., (13):35 p. Food and Agriculture Organization of the United Nations.

Hunn, Joseph B. 1989. History of acute toxicity tests with fish, 1863-1987. SH157.7.I58 no. 98 , United States Department Of The Interior, Fish And Wildlife Service Series.

International Joint Commission (IJC) 1950. Pollution of boundary waters. International Joint Commission, Washington D.C., Ottawa, Canada.

MacGregor, D. J., and Wells, P. G. 1984. The role of ecotoxicological testing of effluents and chemicals in the Environmental Protection Service: A working paper. Environment Canada, Ottawa, Canada.

National Academy of Sciences. 1972. Water Quality Criteria 1972. Washington, D.C., USA.

Ontario Ministry of Environment and Energy. 1994. Water Management: Policies, guidelines, provincial water quality objectives. Toronto, Canada.

Ontario Ministry of Environment (OMOE), 1969.Water saga: A story of water management in Ontario 1956 – 1968. Ontario Ministry of Environment, Toronto, Ontario.

Ontario Ministry of Environment. 1978. Water Management: Policies, guidelines, provincial water quality objectives. Toronto, Canada.

Ontario Water Resources Commission. 1967. Policy guidelines for water quality control in the Province of Ontario. Toronto, Canada.

Ontario Water Resources Commission. 1970. Policy guidelines for water quality control in the Province of Ontario. Toronto, Canada.

Sergy, G.A. 1987. Recommendations on aquatic biological tests and procedures for Environmental Protection, Conservation and Protection, Department of the Environment. Environment Canada, Ottawa, Canada.

Servizi, J.A., Stone, E.T., and Gordon, R.W. 1966. Toxicity and treatment of kraft pulp bleach plant waste. Int. Pacific Salmon Fish. Comm., Progress Report No. 13. New Westminster, Canada.

Sprague, J.B. 1969. Measurement of pollutant toxicity to fish. I. Bioassay methods for acute toxicity. Water Res. 3(11):793-821.

Sprague, J.B. 1970. Measurement of pollutant toxicity to fish. 2. Utilizing and applying bioassay results. Water Res. 4(1):3-32.

Sprague, J.B. 1971. Measurement of pollutant toxicity to fish. 3. Sublethal effects and “safe” concentrations. Water Res. 5(6):245-266.

Sprague, J.B. 1973. The ABC’s of pollutant bioassay using fish. In Biological methods for the assessment of water quality. Edited by J. Cairns, Jr. and K.L. Dickson. American Society for Testing and Materials, Philadelphia, USA. pp. 6-30.

Sprague, J.B. 1996. An informal look at the parents of Canadian aquatic toxicology. In Proceedings of the 22nd Annual Aquatic Toxicity Workshop: October2-4, 1995, St. Andrews, New Brunswick. Edited by K. Haya and A.J Niimi. Can. Tech. Rep. Fish. Aquat. Sci. 2093. pp. 2-14.

Taylor, L.N., Doe, K.G., Scroggins, R.P., and Wells, P.G. 2013. Regulatory ecotoxicology testing in Canada: Activities and influence of the Inter-governmental Ecotoxicological Testing Group. Water Qual. Res. J. Can. 48(1): 14-29.

U.S. EPA , 1988. History of the U.S. Environmental research laboratory at Duluth, MN from its inception through 1987. EnvironmentaI Research Laboratory-_Duluth, U.S. EPA

CHAPTER 3

Structure, Function and Governance of ATW/CEW

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Subsequent meetings of ATW over the first 14 years quickly attracted between 125 and 150 attendees annually as the venues cycled across the country to eastern, central, and western locations. The 1990 Vancouver meeting experienced a huge jump in attendance to 440 as a result of Peter Chapman's strong promotion of the workshop on the west coast and into the U.S. That year's attendance set a record that has been closely approached but not yet exceeded (Figure 1). Attendance levels between 300 and 400 continued over the years until 2011, when attendance dropped to pre-1990 levels due to the effects of the 2008 - 2009 global economic collapse. Attendance recovered to 300 by 2014 but were reduced again from 2019 to 2022 due to the COVID pandemic. In fact the meeting was canceled in 2020 and when held in 2021, many attended by video conference making it the first "hybrid" meeting. It was repeated the following year but thereafter the Board decided to discontinue the practice once COVID had dissipated.

Presentations throughout ATW/CEW have always been abundant, with 56% of attendees making either platform or poster presentations on average over all years and some years being in the high 60% participation. The presentation of posters did not really take hold until 1987, although there were several earlier years with some posters (most with none). Once established, poster presentations comprised about a third of total presentations. Mini-workshops and panel discussions were more popular prior to 1994, at which time they dropped off the program (Figure 1). The 2012 membership survey indicated an interest in re-

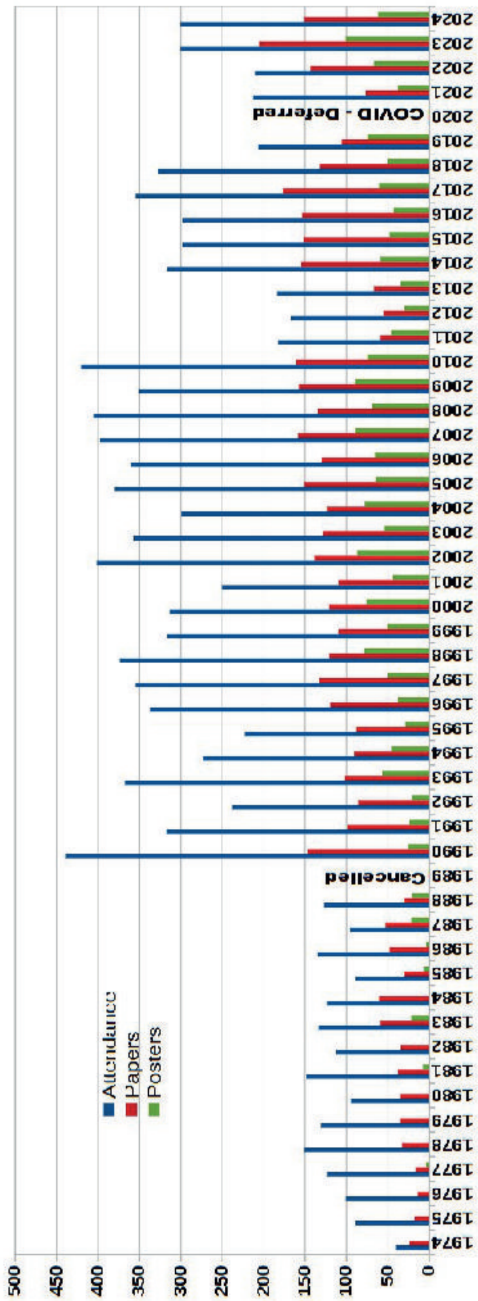

Figure 1: **Attendees, papers, posters and workshops over 50 years**

instating workshops.

Half- and full-day short courses on many different topics were introduced in 1996, either in classroom, local laboratories, or field settings. They continue based on the interest of instructors stepping forward and the program plans of the local organizing committee.

The workshop has reflected the pressing issues and needs of the day through its program and by providing a venue for complementary groups—the CCME working group developing multi-media quality objectives, the Inter-Governmental Ecotoxicological Testing Group (IGETG) developing national test methods, Environmental Effects Monitoring (EEM) technical working groups, oil sands working groups and international working groups, which have often held meetings in conjunction with CEW.

Local Organizing Committees

Every year, the CEW Board of Directors canvasses for potential Chairs of future meetings, usually approaching individuals two to three years in advance. Chairs or Co-Chairs then engage colleagues to form a local organizing committee to plan and manage the workshop. The organizing committee has complete autonomy to invite guest speakers, promote key issues and set the theme of the workshop. In 2002, Peter Chapman authored the first version of the Board's standard operating procedure (SOP) to assist local organizing committees in setting schedules to complete tasks so they would benefit from lessons learned in the planning and implementation of past workshops. The SOP has been updated annually based on recommendations from each retiring organizing committee.

Over the past years, 84 individuals have chaired an ATW/CEW, with a few serving as chair a number of times (Table 1). Over 500 people have participated on organizing committees (Appendix 1) during that period. The commitment of chairs and organizing committee members across the country and within every province has enabled the workshop to continue year after year.

Governance

Until 1980, provincial or federal institutions hosted and assumed the financial risks of conducting the conference providing administration and meeting rooms. The preceding Chair of the workshop passed on materials and suggestions for the logistics of the next meeting, but that was all.

Table 1. Individuals chairing multiple ATWs		
Three-term Chairs		**Institution**
Raymond Van Coillie	1988, 1993, 1998	Environment Canada
Gordon Craig	1975, 1981, 1997	Ont. Min. Envir./ BEAK
Two-term Chairs		
John Davis	1974, 1977	Fisheries and Marine Service (DFO)
Earl Baddaloo	1992, 1999	Alberta Environment
Scott Munro	1994, 2005	Sarnia-Lambton Industrial Envir. Ass.
Peter Wells	1976, 1983	Envir. Canada / Dalhousie University
Karen Mathers (Honorary)	2001, 2011	TetrES / Stantec
Graham van Aggelen	2002, 2012	Environment Canada
Curtis Eickhoff	2002, 2018	BC Research / Nautilus Environmental
Les Burridge	2004, 2013	Department Fisheries Oceans
Karsten Liber	2008, 2015	U. of Saskatchewan

Due to meeting hosts being government institutions any excess sponsorship money was becoming problematic in the transfer to the subsequent organizing committee. In 1980, Sharon Leonard (DFO), who served on the Winnipeg 1979 organizing committee, proposed that ATW be incorporated and a continuity fund be established to underwrite advance hotel booking costs and various other obligations that were becoming necessary to launch subsequent workshops. The formation of a separate organization solved the complexity of advances and financial transfers, and enabled academic and private sector groups to participate in hosting.

Sharon Leonard drafted and filed federal not-for-profit incorporation articles under the name “The Canadian National Aquatic Toxicity Workshop,” which was registered in 1984. Incorporation also required a Board of Directors, and, as no one was looking for a lifetime appointment, a rotation mechanism was worked out. The Board would have a Continuity Chair held by a federal government employee which was first held initially Keith Marshall and later by Mike Gilbertson both from the EC Canadian Wildlife Service. When Mike Gilbertson moved to DFO, Peter Wells on assignment in Ottawa with EC worked with Mike to arrange for DFO to take over publishing the ATW proceedings as a Technical Report Series. Until then the proceedings were published by the host provincial or federal agency of the workshop.

The other directors on the Board would be the Chairs of the previous, current, and following year’s workshops. Funds, held in a separate ATW corporate bank account, would be managed by the Continuity Chair, who also edited and published the proceedings. Directors would rotate on and off the Board on a three-year cycle. ATW was productively governed in this way for the next 22 years (Figure 2).

Once the continuity fund was established under Sharon Leonard a mechanism was in place to accumulate excess funds from growing sponsorships and provide seed money for subsequent organizing committees. Deposits were required by hotels to hold blocks of rooms as much as three years in advance. As the meeting date approached travel arrangements for speakers and student Board advisors were financed. The three year planning schedule required enough cash to cover debts from the last meeting, pay for current year expenses and seed the next meeting. Receivables were not deposited and credits from hotels were not realized until after each meeting had finished. The Board had administrative costs and

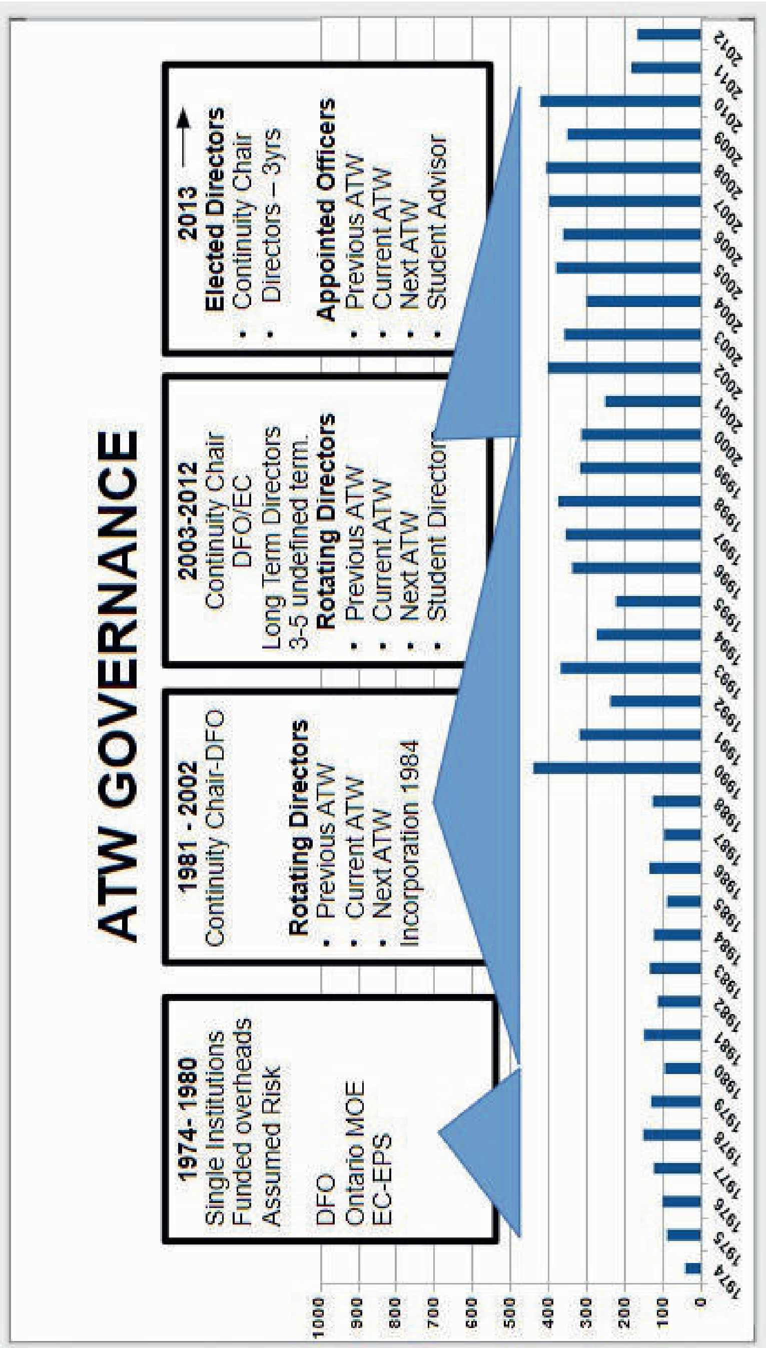

Figure 2: Evolution of ATW governance over 50 years

after becoming CEW, retained an accountant to audit annual financial statements. Further, as the student program matured, the continuity fund financed presentation awards, the Playle award and travel assistance awards. Maintaining a fluid cash flow was critical to a viable ATW operation to foster succession in the long term.

In 2002, the Board decided that more permanence was required to assist the Continuity Chair and strengthen the corporate memory of ATW. The designation of "Long-term Director" was created with an indeterminate term, and that position would be appointed by the board. The other directors would rotate through as before. Art Niimi was the Continuity Chair at the time, and Scott Munro and Gordon Craig became the first long-term directors.

Ten individuals have held the position of ATW Continuity Chair since conception, with Art Niimi having the longest standing of 19 years (Table 2). After 2013 the position became "President". DFO supported ATW by allocating a portion of the Continuity Chair's professional time to managing the organization and editing and publishing the proceedings. Before word processors and desktop computers became part of the office landscape in the 1980s, publishing the proceedings was a substantial task and Art Niimi did most of the literal cutting and pasting during those years.

New federal legislation came into force in 2011 that required a number of changes to the governance of "not-for-profit" corporations, which had a direct effect on ATW. Key changes included election of directors by the membership, the appointment of a public accountant, annual reporting to Corporations Canada and Canada Revenue Agency, and making year-end financial statements available to the ATW membership. Rosalie Allen Jarvis took on the Herculean task of creating the first set of ATW articles and by-laws in 2012 to meet the new legislative requirements.

Members at the 2013 meeting in Moncton approved new articles of incorporation and by-laws and a Certificate of Continuance was issued by Industry Canada in December of that year. The first directors elected to the corporation in 2013 for a three year term were Rosalie Allen Jarvis, continuing in her role as Continuity Chair, Gordon Craig, and Dave Huebert. Les Burridge was subsequently appointed by the Board as a fourth director for a one-year term. Officers of the corporation, representing chairs of past, current, and future ATW organizing committees, as well as graduate student advisors, were also appointed

Table 2: ATW/CEW Continuity Chairs		
Continuity Chair / President*	**Years of Office**	**Duration**
Sharon Leonard (Honorary)	1979 –1980	2 years
Keith Marshall	1980 –1981	2 years
Mike Gilbertson	1981 –1986	5 years
N.Y Khan	1986	1 year
Art Niimi	1986 – 2005	19 years
Les Burridge	2005 –2011	6 years
Rosalie Allen Jarvis *	2011 – 2017	7 years
Lisa Taylor*	2018 – 2020	3 years
Carrie Rickwood*	2021 – 2024	4 years
Ryan Prosser*	2025 - present	1 year

by the Board. The officers would rotate on a three-year cycle as they had done as directors previously.

Workshop Expansion of Scientific Scope and Transformation from ATW to CEW

At the 2012 workshop in Sun Peaks, BC a panel constituted by Karsten Liber, Rick Scroggins and Peter Chapman led a discussion forum on the future of the ATW with attendees. The topics were wide ranging including workshop identity, proposed new names to reflect an expanded scientific scope, different promotion approaches, format suggestions, ideas to enhance scientific program, suggestions to encourage more involvement from Canadian industry, timing of meeting and locations for future workshops.

This session led to a decision by the ATW Board to create an Advisory Committee (AC) to help in addressing some of the ATW member suggestions for change (Table 3). The Board also sent out a survey to workshop members in late 2013 to assess the level of interest in a broader scope of scientific topics from the full ATW membership. In the summer of 2014, a second, more focused questionnaire was sent to members to ask if they supported an expanded scientific scope for future workshops and a change in workshop name to better reflect this change.

Rosalie Allen Jarvis, Chair of the Board, presented the findings of the 2014 survey that 75 percent of respondents supported an expansion of the scope to the workshop as long as the traditional aquatic toxicology sessions were retained. Examples of non-aquatic session topics for future workshops included wildlife toxicology, soil toxicology, risk assessment, and environmental guideline derivation. Across all membership categories, a clear majority of respondents supported the proposed change of workshop name to the Canadian Ecotoxicity Workshop (CEW). The meeting name change was officially announced during the 2014 ATW in Ottawa.

The Board, with membership authorization, had already changed the governance structure to comply with new “not-for-profit” regulations in 2013 so a name change a year later was timely.

The CEW Board was officially responsible for:

- CEW Continuity Fund management accumulated from past workshops
- soliciting, reviewing and selecting proposals to host future CEW
- appointing OC as Co-chairs as Officers of the corporation;

Table 3 : Advisory Commitee 2013 - 2025

Advisory Committee Chair	**Members 2013 – 2025 - Consolidated**
Rick Scroggins Environment Canada 2013 - 2017 Karsten Liber U. of Saskatchewan 2018 to 2025	Julie Anderson – Stantec Consulting Caroline Côté - Université Laval Charles Dumaresq – The Mining Assoc. Canada Curtis Eichoff - Nautilus Environmental James Elphick –Nautilus Environmental Guy Gilron – Borealis Environmental Dave Huebert – Stantec Consultants, Vancouver Sarah Hughes – Shell Karsten Liber - U. of Saskatchewan, Saskatoon Pierre Martel – FP Innovations, Pt. Claire Rick Meyers – Mining Association of Canada Tim Moran – TAMM Consulting Jorgelina Muscatello – Lorax Environmental Patti Orr – Minnow Environmental John Purdy – Abacus Consulting Rick Scroggins – ECCC Paul Sibley – University of Guelph Judit Smits – University of Calgary Lisa Taylor – ECCC Gerald Tetreault – ECCC Laura Tupper-Ring – Dillon Consulting Leana Van der Vliet – ECCC Anne Wilson – ECCC ECCC-Environment and Climate Change Canada

Figure 3: CEW Corporate loge created and presented in 2016

- advising and supporting current and future OCs;
- appointing Graduate Student Advisors as Officers of the corporation
- appointing the Playle Award Selection Committee; approve recipients
- management of Playle Award reserve funds
- managing the Student Travel Grant Program
- appointing members to the Advisory Committee to the Board
- ensuring compliance with federal legislation; fulfillment of federal reporting requirements for not-for-profit corporations; and
- updating the workshop Standard Operating Procedure (SOP)

New Logo for CEW

The years from 2012 to 2014 were a period of dramatic change with introspection, the need to register for a Certificate of Continuance as a not-for-profit, a re-stating of articles of incorporation and a name change to Canadian Ecotoxicolgy Workshop. The Board felt that it was also timely for a standardized corporate logo. In the past OCs generally followed the water drop format but also used the opportunity to design a new logo that reflected the host city or venue. There were a wide range of variations but they were not consistent with branding. The 2015 organizing committee created a particularly striking logo that captured the three basic elements of air, land and water which was considered by many as consistent with the name change and emphasis on ecotoxicology. The Board appointed Gordon Craig, a director, to form a focus group to develop a number of concepts and work with a graphic artist to design a suitable logo that the Board could approve.

The designer of the Saskatoon logo, Manu Chávez-Ortiz, a recent graduate of the Centre for Toxicology, was retained to work on the new design and set up the graphics specifications for future venues. The Saskatoon water drop shaped logo was modified by adding a gradient of colours to the land to represent agricultural fields, uplands and mountains. Three birds were added to a blue sky. The water component contained a fish in keeping with ATW's historic tradition and it was given a double helix tail and body to tie the biological components together. The corporate logo is presented in Figure 3 and the venue name would be placed under the text.

Student Program

Presentation Awards

The ATW Board established a student program, beginning with awards for for

Peter Chapman

Art Niimi

Richard Playle

best student paper and poster in 1991. The Board expanded the student awards program increasing the awards to three for each of platform and poster presentations with cash prizes in 2000. In 2018 the Board named the platform awards in the memory of Dr. Peter Chapman and the poster awards were named to honour Dr. Art Niimi, the longest serving continuity chair. Both had contributed significantly to the growth and development of ATW/CEW (Figure 4).

Peter Chapman 1951-2017

Peter was the catalyst for the ATW/CEW student awards program initiating an EVS Consulting prize in 1991 for best student platform and poster presentation. He prepared the first version of the ATW/CEW standard operating procedure (SOP) for the planning and operation of our meetings. Peter received the SETAC Founders Award in 2001; participated in the NSERC Metals in the Environment and Metals in the Human Environment research network; sat on North American Metals Council's Selenium Workgroup; the Environment Canada committee to implement the Canadian Environmental Protection Act; and US Environmental Protection Agency's Science Advisory Board. He authored over 230 peer reviewed articles, edited three books, was an editor of three international peer reviewed journals, made over 300 presentations at meetings, and authored over 400 technical reports. He advised governments in Canada, United States, Australia, Peru and the Association of Southeast Asian Nations on environmental issues.

Art Niimi 1941-2023

Art was a research scientist with Fisheries and Oceans Canada who monitored contaminants in Great Lakes fish and contributed to the CCME protocol for establishing tissue residue guidelines to protect wildlife consumers of aquatic biota and contributed to the development of food web models to predict contaminant concentrations in aquatic biota. Art became the ATW continuity chair in 1986 and served until 2005. As such he was responsible for managing the continuity fund and providing subsequent organizing committees with initial financing for each workshop. His other duty was to compile the proceedings from each workshop and publishing them as a DFO Technical Report series providing referenceable material. In those early days this required literal cutting and pasting of pages prior to printing. As word processing became more widely available time and effort was reduced but Art continued to publish these reports throughout his tenure. He also guided organizing committees over the years until

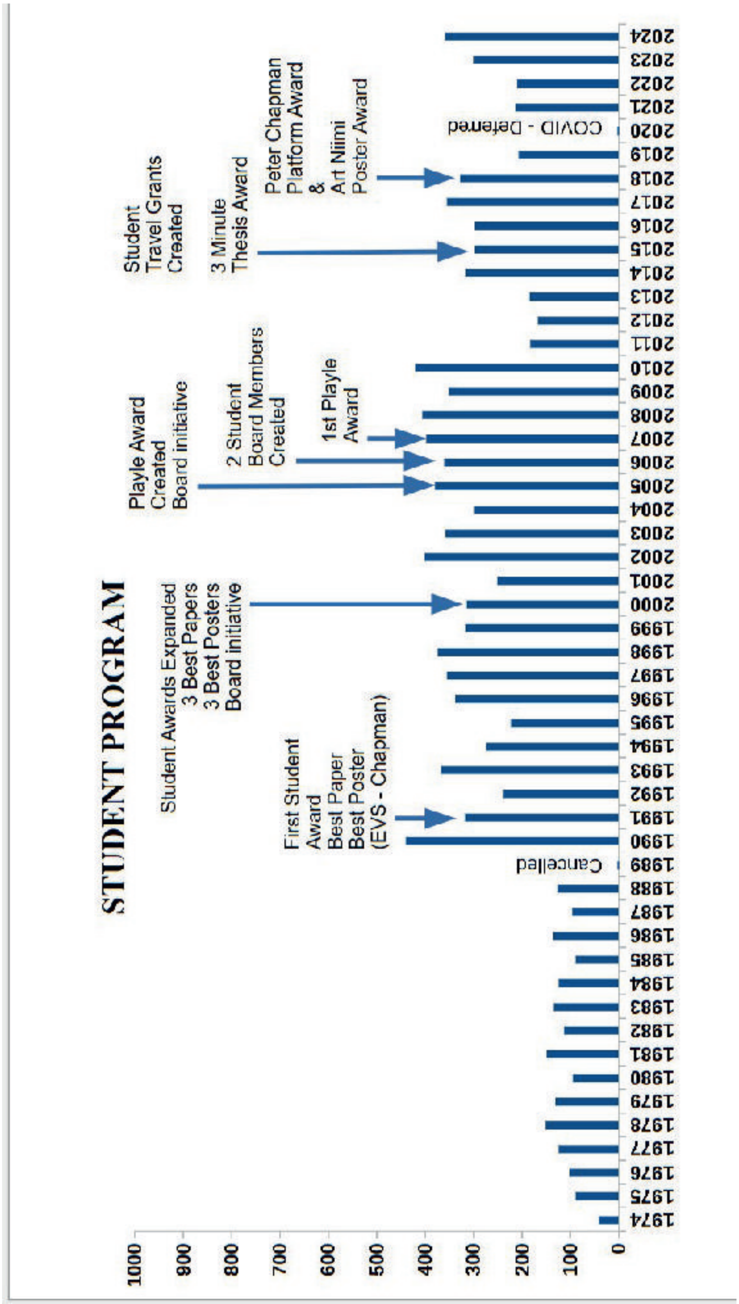

Figure 4: Chronology of the ATW / CEW student program

a board of directors assumed more of those responsibilities. Art was an important factor in the early development of ATW and his contribution was commemorated in 2018 by dedicating the Outstanding Student Poster Award in his name.

Playle Award – B.Sc. and M.Sc Thesis

In 2005, the Waterloo organizing committee created the Playle Award in memory of Dr. Richard Playle, of biotic ligand fame; a Professor of Biology at Wilfrid Laurier University from 1992 to 2005. The award recognizes theses for both Honours B.Sc. and M.Sc. graduates. Students may submit their theses with their supervisor's and department chair's approval and winners of the award must present their work at the subsequent ATW; their travel expenses and one day's registration are subsidized by the Board. The list of Playle winners since 2007 is presented in Appendix II.

Student Advisors to the Board

In 2006, the Board created two student positions to foster interest in the governance of ATW. The student advisors positions are staggered alternative years so one student rotates on and another rotates off each year. They receive full registration and travel costs for their term.

Student Travel Grants

In 2015 student travel grants were created to encourage attendance and the number is determined by the strength of the continuity fund. Students can apply for a grant if the meet the following criteria:

- they are enrolled as a student in a Canadian university
- they will deliver a platform or a poster presentation
- they have not previously received a CEW attendance grant
- they are willing to volunteer in the CEW student program.

The chronology of the CEW student program is presented in Figure 4.

CEW Outstanding Contribution Awards

Established in 2017, the CEW Award for Outstanding Contribution to Canadian Ecotoxicology recognizes individuals who have made a significant and measurable contribution to the field of ecotoxicological science in Canada. Nomination package submissions are accepted by June 1st each year and a committee led by a member of the CEW Board of Directors selects the recipients. Nomination requires a CV, a justification rationale drafted by a member sponsor and up to three references attesting to the merits of the nominee. The award is bestowed upon the recipient(s) at a subsequent CEW annual meeting. To date, there have been 16 individuals who have received this prestigious CEW award.

Award Recipients with summarized descriptions * :

Keith Solomon - 2017

Dr. Keith Solomon has been professor at the University of Guelph since 1978 and has supervised 73 graduate students, 6 post-doctoral fellows, 24 research associates, 32 technicians, 30 summer students and countless undergrads in their research projects – many of whom have gone on to hold prominent positions in the ecotox community. His research on the risk assessment of chemicals, the use of mesocosms to investigate the effects of chemicals, fate and effects of herbicides applied in forestry and the fate of contaminants in Canada's arctic has resulted in 289 peer-reviewed journal publications. His highly cited review on the ecological risk assessment of atrazine has influenced regulatory decisions on atrazine in Canada, the USA and Europe and advanced the use of probabilistic risk approaches to manage pesticides in general. He has also made important contributions to the ecotoxicological hazards and risks of endocrine-active substances and has had a long standing risk assessment role on the Environmental Effects Assessment Panel of the Montreal Protocol on the effects of ozone depleting substances.

Keith Solomon is the Kevin Bacon of Canadian toxicology! At some point in your career, you will have taken his course, read his paper, attended a meeting he hosted, or been mentored by or collaborated with Dr. Solomon.

****** The following descriptions of award recipients are from the CEW website and have been augmented from copied comments of the respective nominators and supporters.***

David Poirier - 2017

David Poirier has been a senior scientist at the Laboratory Services Branch for the Ontario Ministry of the Environment and Climate Change for the last 30 years. Mr. Poirier was instrumental during the initial days of effluent testing programs for regulatory purposes and withstood severe criticism from industry representatives in the defense of toxicity testing methodologies. He has successfully defended those results in many pivotal court cases. Dave has been instrumental in the development of Ontario water quality guidelines for neonicotinoid pesticides, biosolids, hydrazine, de-icing fluids, heat transfer agents and fire-fighting foams. Dave has supervised the aquatic toxicity unit laboratory at the MOECC for 30 years and been instrumental in the development of a number of standardized test protocols (e.g., Daphnia magna acute lethality toxicity test protocol; MOECC Bioaccumulation of sediment-associated contaminants in freshwater organisms), the publication of numerous outstanding manuscripts. His perspective on ‘industry partnership with government’ supports the public’s goals of keeping water drinkable, swimmable and fishable. He is also a Special Graduate Faculty at the University of Guelph and has directly mentored over 300 students and staff in projects that have led to the refinement and improvement of culturing and toxicity testing methods.

Vance Trudeau - 2017

Dr. Vance Trudeau is professor of neuroendocrinology at the University of Ottawa and the “Trudeau Family Tree” includes 50 Honours Bachelors of Science graduates, 14 Masters of Science graduates, 27 doctorate and 6 post-doctoral fellows; an incredible investment in the next generation of environmental scientists. He has been at the leading edge of his discipline in terms of identifying and characterizing the neuroendocrine system as a target for the effects of chemicals in the environment and has published over 250 peer-reviewed journal articles. Dr. Trudeau was one of the first in Canada to incorporate molecular endpoints into ecotoxicology including the application of OMICS tools into ecotoxicology that are now used more routinely in the field. He was the first to formally define neuroendocrine disruption and to conduct molecular toxicology studies in amphibians. He has also worked with naphthenic acids to conduct ultrasensitive tests on oil bi-products. Dr. Trudeau is considered a pioneer in using molecular biology techniques to study neuroendocrine regulation in fish and frogs; these tools are now applied widely in the environmental arena.

Karsten Liber -2018

Dr. Karsten Liber is Director of the Toxicology Centre at the University of Saskatchewan (UofS) where he has mentored 29 MSc students, 9 PhDs, 5 post-docs, and 8 undergraduate thesis students. His publication record includes 104-peer reviewed publications on a wide variety of topics that can best be categorized as applied toxicology and reclamation, and his research aims to work with industry partners to find solutions to real-world challenges, from oil sands to uranium mines to pesticides. His research has been used in the derivation of national environmental quality guidelines for the protection of aquatic life, the development of site-specific water quality objectives and to guide reclamation targets at contaminated sites.

Karsten has been instrumental in establishing programs at the UofS and other organizations such as the Northern Ecosystems Toxicology Initiative (NETI), the Canada Excellence Research Chair in Water Security (Dr. Howard Wheater) and the Global Institute in Water Security (GIWS), the largest water research program at any academic institution the world. He also led the Canada Foundation for Innovation proposal for expansion of the UofS Toxicology Centre in 2007-08. While he was the president of the Society of Environmental Toxicology and Chemistry (SETAC) North America (2015-16), he oversaw numerous initiatives that included public outreach, professional certification for environmental toxicologists, and global horizon scanning for the most important environmental toxicology issues facing the world today.

He has always been a big supporter of CEW and, in addition to actively participating himself, he has also encouraged his students to do the same. Dr. Liber found time to co-chair two ATW meetings in Saskatoon, regularly serve on CEW organizing committees, chair the Advisory Committee to the CEW Board of Directors since 2017, and serve two terms on the Board. Dr. Liber's true legacy is one of relationship and capacity building– a great dynasty of toxicology as it were. According to his nominator, "the Canadian ecotoxicology landscape has been transformed as a result of the Toxicology Program [that] Dr. Liber has built at U of S."

John Sprague - 2018

Over his career, Dr. Sprague has worn many hats in the world of ecotoxicology, from Scientist-in-Charge at the Fisheries Research Board of Canada, to Associate Professor at the University of Guelph, and finally President of his own consulting company. He supervised 15 M.Sc. students, 7 Ph.D. students, and 1 post-doc, plus served on committees of 48 other students at Guelph, Waterloo, McGill, University of New Brunswick and in Australia. He has sat on over 50 advisory panels, editorial boards and committees across Canada and internationally. He was also actively involved in SETAC and community organizations on Salt Springs Island for many years. He has a considerable publication record, with 65 peer reviewed papers, chapters, and a book; 115 technical reports and book reviews, and numerous unpublished consulting reports and presentations at conferences. John contributed to the 1961 APHA Standard Methods bioassay section and one of the first water quality criteria published in 1972 by the US National Academy of Sciences.

He published three papers in Water Research "Measurement of pollutant toxicity to fish" and a summary document "The ABCs of fish toxicity" in the early 1970s. These papers consolidated current varied practice and incorporated established pharmacological principles that were lacking in previous methods.

His papers were so well received that the first of the series qualified as a SCI Citation Classic.

He was one of the co-authors of the Environment Canada Biological Test Methods for acute lethality in rainbow trout and Daphnia species, among other key Environment Canada guidance documents. John's fundamental contribution to environmental protection and conservation of water quality in Canada has been to determine the governing factors of reliable and reproducible toxicity testing and create standards for the conduct of those tests.

Rick Scroggins - 2018

Rick Scroggins began his career at BEAK Consultants in the fish toxicity lab. In 1984, after several years of managing the lab and building one of the early mobile toxicity labs in a trailer for on-site effluent testing, he moved on to Environment Canada. Over his many years with Environment Canada, he has been committed to developing scientifically-defensible toxicity test protocols that meet the needs of government and industry. Rick's contribution to environmental science in Canada has been to provide a platform for standardized biological test development to measure and monitor the biological quality of discharges and receiving environments.

Rick also spearheaded the development of the Environmental Effects Monitoring (EEM) program that relied on many of the early acute and sublethal freshwater and marine test methods. He managed the contract to develop the first Technical Guidance Manual that detailed the procedures of the program and interpretation of data. The EEM requirements came into effect in 1992 and was applied first to the pulp and paper sector followed by the mining sector. The program design was also adopted and adapted by other industries to prepare for greenfield developments, prepare for permit applications to change processes and conduct routine monitoring of their operations.

As stated by one of his nominators, "Rick's vision was not just updating the testing requirements of national effluent regulations but to develop a suite of standardized biological test methods for incorporation into different Fisheries

Act and CEPA regulations as either compliance testing or monitoring requirements". Mr. Scroggins has also been a dedicated supporter of CEW, attending most workshops, chairing sessions and serving as the Chair of the Advisory Committee to the Board of Directors from 2013 to 2017. The 152 career presentations that he has delivered at meetings and workshops around the world have played a significant role in elevating Canadian ecotoxicology on the world stage, as have his participation in SETAC, ISO and a number of other professional organizations. The Canadian regulatory and toxicity testing landscape owe no small debt to Rick's dedication, collaborative approach, and perseverance.

Christian Blaise - 2019

Dr Blaise has dedicated much of his research to developing micro-testing methods but that doesn't mean his contribution to ecotoxicity is small! His commitment to improving the science of toxicity testing has vastly improved the understanding of multi-trophic, sub-lethal and genotoxic effects in environmental assessments. Christian, together with colleagues at the Centre Saint-Laurent in Montreal, developed a testing approach called the "Potential Ecotoxic Effects Probe" or PEEP that incorporated a microplate algal test, Microtox, Ceriodaphnia lethal and reproductive test, SOS genotoxicty, Hyda lethality and sublethality, five day biodegradation (persistence), a loading measurement and expression of an integrative logarithmic index. This assessment protocol was applied to discharges from Montreal to Baie-Comeau and Rivière-du-Loup as part of the Saint-Lawrence River Action Plan (SLAP) from 1988 to 1998. It was the fist broad based environmental monitoring program in Canada. These lethal, sublethal and genotoxicty battery of tests could be conducted within seven days on a single sample and they represented a huge advance in ecotoxicity assessment. Throughout his career Christian focused on developing and refining micro toxicity tests not only for point source samples but also for sediments, pore waters, precipitation, surface waters, chemicals and nano materials. He further developed in-situ protocols relying on biomarkers in mussels to detect responses to endocrine disruptors and pharmaceuticals. The microscale ecotoxicity methods he developed and refined attracted use by other countries for their simplicity, size and relatively short turnaround. Christian promoted this technology transfer in Brazil, France, Hong Kong, Thailand and Spain.

As head of the Aquatic Toxicology Unit, River Ecosystems Research Section at Environment and Climate Change Canada and later Emeritus scientist, Christian worked tirelessly to develop and improve bioassays and biomarkers to assess a multitude of contaminants. He has co-edited three major books in the field of ecotoxicology, co-authored over 220 scientific articles and was a member of the editorial Board for several scientific journals. In addition his commitment to knowledge transfer both nationally and internationally has facilitated decision making for environmental management around the world.

Rosalie Allen Jarvis - 2019

Rosalie has been a pillar of CEW and an integral part of this community and we owe much of the success of CEW to Rosalie's dedication and tireless commitment over the last 16 years. Her roles in CEW started back in 2003 when she was part of the Organizing Committee for Charlottetown, PEI. Her role has changed and evolved over the years with her most significant contribution as President, Chair, Treasurer and Secretary (all at the same time) for the board of directors – don't ever underestimate her dedication and multi-tasking abilities! Rosalie assumed the Board Chair role in 2011 just as federal legislation instituted new requirements for "not-for-profit" organizations. By 2013 Rosalie had re-stated the ATW articles and by-laws of incorporation, reset financial reporting to Revenue Canada and established the formal election of Directors by the members as required by the new statutes. In so completing, Rosalie created a functional corporate foundation for the governance and financial stability of ATW. Rosalie has governed and led her Board effectively over the seven years of her Presidency effecting succession, establishing financial security for the corporation to fund an extensive and innovative student program, assuring seed funding for subsequent conferences and supporting each organizing committee with wisdom and experience and championing their esprit de corps.

CEW has undergone a number of changes and faced a number of challenges over the last few years, and as one of her nominators stated it was Rosalie's dedication and organizational talent as President that CEW remains a successful Canadian Institution. It would be remiss to not mention her charismatic and engaging personality which is particularly evident in her ability to convince you to Chair a CEW. Her diplomacy and wicked sense of humour will be missed at board meetings. It is no small task to keep a room full of scientists on point.

Peter Campbell - 2019

Dr. Peter Campbell has had a long and very distinguished career and has been described as "one of the most renowned biogeochemists in the world". It is particularly poignant that he receives this award in Quebec as he was one of the founding researchers at the Water Research Centre at INRS when it opened in 1970 and where he remains Professor Emeritus to this day. He was admitted to the Royal Society of Canada in 2002. His research has been on the toxicity to aquatic organisms of metals based on their speciation and kinetics of uptake within a geochemical environment. He has developed exposure models to predict biological responses based on these interactions and environmental conditions. He has made major contributions to the development of "bioavailability-based methods" for the assessment of metals in freshwater environments (Free Ion Activity Model, FIAM → Biotic Ligand Model, BLM). This knowledge and experience has been important to developing environmental risk assessment approaches that treat metals in a manner that is consistent with their unique properties and their differences from typical organic contaminants.

It is evident from the many graduate students (48) and post-doctoral fellows (24) that he has supervised that he is a much-respected mentor and role model for the next generation of scientists. Of particular note is his service to communities and Canadian First Nations where he has worked for many years to address the practical issues of environmental assessment, preventative measures and remediation. He has over 200 peer-reviewed publications, has chaired or helped organize many symposia and conferences and has been invited to numerous national and international committees and meetings. He has been an ardent supporter of ATW/CEW participating on three organizing committees. Dr Campbell's commitment to disseminating and promoting the science of ecotoxicology both nationally and internationally has been outstanding.

Jennifer Miller - 2021

As an external test method writer, Jennifer has been instrumental in establishing the reputation of Environment and Climate Change Canada (ECCC) as a global leader in the development and standardization of the biological tests under the Biological Test Method Series. She has led the preparation of 5 published ECCC biological test method documents, 2 new methods currently under development and contributed to the technical content of 7 new or amended method documents in the ECCC series. Jennifer prepared the program description for ecotoxicology lab accreditation, a laboratory inspection manual, developed a process for certification of Canadian ecotoxicology testing laboratories and designed the first set of test-specific checklists for use by CAEAL (Canadian Association for Laboratory Accreditation) toxicology assessors during ecotox laboratory inspections.

Jennifer's contribution has ensured Canada has some of the best ecotoxicology testing methodologies in the world and as one of her nominees stated "her contribution to this 25-year effort is something to be proud of and is acknowledged by many Canadians and international ecotoxicology practitioners." Jennifer continues to support CALA through her consulting firm Miller Environmental Sciences Inc, in numerous roles (e.g. lead assessor, quality assurance officer). Her work was instrumental in the successful implementation of the biological tests methods by Canadian accredited laboratories which ensures the production of reliable quality data. Jennifer has given over 15 presentations at CEW and contributed as co-author in many other presentations but as one of her other nominees stated "Jennifer's strength lies in her behind-the-scenes contribution and her diligence, scientific integrity, her ability to collaborate and her willingness to ensure that the tedious nature of science can be fun".

Karen Kidd - 2021

Dr. Kidd has undoubtedly contributed significantly to the ecotoxicology landscape in Canada and her research was described by her nominators as, "highly innovative and impactful.". Dr. Kidd has worked on a wide range of different issues including organic contaminants (PACs, DDT, PCBs, EDCs, toxaphene, herbicides), metals (mercury, cadmium), aquaculture, forestry management, and wastewater. She has pioneered the use of stable isotopes, amino acids, and many other cutting-edge techniques that are now widely used in ecotoxicology. Dr. Kidd has worked in a variety of different aquatic ecosystems including boreal lakes, streams, and marine and estuarine systems.

Her decade-long research looking at whole lake effects of the birth control pill led to significant national and international changes in policy regarding disposal of pharmaceuticals, and to date, her keystone paper on fish population collapse due to estrogen exposure has been cited over 2000 times. Dr. Kidd has an impressive publication record (at least 149 refereed publications), has supervised over 30 Master's and PhD students, and has received numerous national and international awards. She has also been the recipient of both Tier 1 and 2 Canada Research Chair positions and is currently the Stephen Jarislowsky Chair in Environment and Health at McMaster University. In addition to her impressive research record, it was strongly noted by her nominators and supporters that Dr. Kidd's value as a ecotoxicologist stemmed not only from the quality of her research, but from her strength as a collaborator. To quote one of her colleagues, "she is widely sought as a collaborator. This is because she is not only an excellent researcher, but also an outstanding team member." In addition, Dr. Kidd is also a dedicated mentor and advocate for Women in Science, and a positive role-model for women and girls pursuing careers in science.

Peter Wells - 2021

Over the last 50 years, Dr. Wells has dedicated his career to the protection of the marine environment through his work on the impact of oils and dispersants on marine organisms, and on the development of ecotoxicity testing. Dr. Wells joined Environment Canada in 1974 at the Bedford Institute of Oceanography. Through his work at ECCC and his involvement with the Environmental Information: Use and Influence research program at Dalhousie, he has contributed significantly to the use of scientific evidence in policy making, specifically related to the protection of marine environments.

In the 1980s Peter chaired the Environment Canada Marine Environmental Quality Advisory Group, sat on the Marine Board Committee of the National Academy of Sciences to characterize the impact of contaminants on the marine environment. He became actively involved in Gulfwatch : Chemical Contaminants Monitoring Program sponsored by the Gulf of Maine Council on Marine Environment in which he continues to serve. Gulfwatch is an international, intergovernmental program among Canada and the United States, provinces and states which hosts annual meetings at which Peter has made numerous presentations on the health of the Bay of Fundy ecosystem. In 2006 and joined the Dalhousie School for Information Management (SIM), Marine Affairs Program where his interest further evolved to the study of science–management–policy linkages focusing on Integrated Coastal and Ocean Management (ICOM). The culmination of his practical experience has led him to developing guiding principles at the science – policy interface of resource management and particularly on ICOM.

He has been a member of numerous national and international committees and advisory boards, working to ensure that science is not excluded or misused in policy creation. Throughout his long and distinguished career, Dr. Wells has been a prolific writer, producing over 300 publications. He has also sat on the editorial board of a number of recognized journals and supervised 25 graduate students. Dr. Wells has developed lasting relationships with his colleagues and collaborators over many years; relationships built on trust, passion for the science, and an eye to interdisciplinary problem-solving where everyone can contribute. He has been a teacher and prolific writer who, with his global connections, has effectively promoted the inclusion of science-based information for the protection of oceans in general and Canada's in particular.

Gordon Craig - 2021

Gordon started his career in ecotoxicology in 1974, the same year that the first Aquatic Toxicology Workshop was held and he presented at that first meeting. After 10 years with the Ontario Ministry of the Environment, Gordon became a Principal with Beak International Consultants building the largest Canadian commercial aquatic toxicity laboratory of its day offering freshwater and marine testing services. In 1997 he started G.R. Craig & Associates where he worked as an independent researcher until 2015. He was a member of the IJC Ecosystems Objective Committee l98l-1986 that developed Great Lakes water quality objectives; chaired the International Secretariat for the ISO Invertebrate Toxicity Methods working group TC147/SC5/WG2 from 1993–2000; was a Canadian delegate on the OECD Expert Panel for the revision of the Principles of Good Laboratory Practice (GLP) 1996-1997. Gordon has dedicated himself to the CEW over its entire history and chaired three ATW meetings including the second in Toronto in 1975. He rotated on and off the Board of Directors between 1984 and 2003 before being appointed for a 10-year term, followed by an elected 3-year term. Gordon's ongoing presence on the Board served to provide stability and strengthen institutional memory of the CEW corporation. He produced the official forty-year history of ATW retrospective, contributed to the re-stating of the 2013 CEW articles and by-laws of the corporation, developed a financial sustainability model for the corporation and registered the original atw.ca and the later ecotoxcan.ca domains. He created and maintained the original ATW website for many years and developed the first administrative software to manage the logistics of the meetings. His participation at the first meeting, hosting of the 1975 meeting, long term Board membership and co-chair of subsequent meetings has resulted in Gordon being considered a founding member of ATW. Having missed only a handful of annual workshops, Gordon is undoubtedly at the heart of the CEW community. As one of Gordon's colleagues puts it, "One cannot reflect on the history of the CEW without also thinking about Gordon Craig. From the initial meetings in the 1970s to leading the design team of the new CEW logo in 2015, Gordon was there." Gordon Craig's lifelong dedication, forward thinking, and desire to build a workshop and community that would outlast him have resulted in this truly special home for Canadian ecotoxicologists.

Kelly Munkittrick - 2023

In his over 30-year career, Kelly has been a leader in Canadian ecotoxicology. He has led research programs on the impacts of oil sands, pulp mills, agriculture, municipal wastewaters, oil refineries and metal and coal mines on fish populations and river ecosystems across Canada. Kelly developed the PISCES (Population Indicators of Sublethal Contaminant Effects on Suckers) framework for interpreting variations in fish population health endpoints. This framework became the basis of the EEM fish community health assessment and has been adapted to other species and has been used around the world. Canada's Oil Sands Innovation Alliance (COSIA), the innovation arm of Pathways Alliance Inc, retained Kelly as their Monitoring Director to consolidate oil sands monitoring programs among fourteen oil sands members and more than ten other associations. He also conducted a series of Monitoring workshops for both COSIA members and regulatory groups like Alberta Environment and the Alberta Energy Regulator bringing industry, consulting, regulatory and academic sectors together.

Kelly is known to many in the ecotoxicology field as a very committed supporter and mentor to students and young professionals in various sectors (i.e., academia, government, consulting). At CEW, Kelly has always been a positive and encouraging supporter of the student programs and has introduced many young scientists to the field through CEW. During his acceptance speech, Kelly stressed the importance of establishing your "science family" during the early years of one's career. These individuals will likely be your closest collaborators and best friends for life.

Mark Servos - 2024

Dr. Mark Servos is an ecotoxicologist who actively promotes solutions for environmental protection and remediation. With over 30 years of experience in government and academia, Mark has advanced environmental risk assessment and management of contaminants in a variety of industrial sectors, including municipal wastewaters. Mark was the Scientific Director of the Canadian Water Network (2003-2011) were under leadership, this national Network of Centres of Excellence fostered partnerships of academia, government, and industry to apply knowledge to create innovation in the water science sector for the purpose of sustaining prosperity and quality of life for Canadians. He was also a leader in the establishment of a national agenda on the scientific assessment of endocrine disrupting substances in our Canadian aquatic ecosystems. He pioneered research on the risk assessment of nonylphenol and its ethoxylates and its threats to sources of drinking water and aquatic ecosystem health. He is internationally recognized for his expertise in a broad range of fields, including dioxins and furans, pulp mill effluent impacts, municipal sewage waste impacts, and the impacts of pharmaceutical and personal care products. He balances the worlds of environmental chemistry and ecology, bringing expertise from both sides to broaden the learning experience for his students. During the recent pandemic he pivoted his research to conduct surveillance of SARS-CoV-2 and its variants in wastewater to inform public health action. His commitment to interdisciplinary experiential learning has influenced many young scientists across Canada.

Paul Sibley - 2024

Dr. Paul Sibley's research interests focus on issues of water quality and its management, including understanding the effects of anthropogenic stressors in agricultural, boreal, and Arctic landscapes; risk assessment of novel, priority, and emerging compounds; stressor interactions and their cumulative effects; and understanding risk perception and communicating risk. He has worked on a wide range of topics from the lab to field at the forefront of ecotoxicology, including perfluorocompounds, pharmaceuticals and a range of pesticides. He has trained over 90 graduate and undergraduate thesis-based students. He has served on numerous professional committees and panels, helped to organize several conferences and workshops (including CEW Guelph), and served as president of two professional societies (SETAC and IAGLR). He has published ~160 papers and book chapters.

Technology

In the beginning days of ATW all correspondence was by letter mail and later, to a degree, by fax. Notices and messages would take a week to be delivered across the country. The development of computer and internet technology had a profound effect on ATW. Affordable desktop computers entered the market in the mid-1980s, reducing the effort of data calculation and publication. The internet became publicly available by the mid-1990s, enabling the instantaneous transfer of text, data and graphics files that previously were printed and sent through the mail. The 1997 workshop co-chair, Gordon Craig, registered the domain ATW.CA and created the first versions of the ATW website and an online registration system that simplified logistics and financial workshop administration. The speed of creativity and communication multiplied yearly so that reports and material for presentation exploded and further contributed to the growth in attendance of ATW in the 1990s. Social media appeared in the early 2000s with LinkedIn, Facebook and Twitter. ATW adopted these communications platforms to further promote the workshops and broadcast announcements.

ATW/CEW Accomplishments

The annual ATW meeting has provided direct personal contact between regulators and industry representatives. Academics have collaborated with federal, provincial, and private research scientists and environmental managers in many studies of mutual interest. Individuals with common interests have published books and papers on the many new technologies, such as the usefulness of microscale toxicity tests or microbiotests (Wells et al. 1997; Blaise and Ferard 2005, Wells and Doe, 2014). The meetings have facilitated a better understanding among all sectors and provided a platform to encourage students and introduce them to potential employment prospects.

The tools of aquatic and terrestrial toxicology have been standardized and refined to measure effects on exposed organisms at orders of magnitude lower concentrations than in the days of ten fish in a bucket. The progress has been astounding. Application of these tools has been embedded in large-scale environmental assessments applied to private and public sector industries operating in the country. Environmental Effects Monitoring (EEM) has been developed, refined and expanded to include community based monitoring (CBM – see Chapter 8) incorporating citizen scientists, school groups and indigenous communities with cultural knowledge. The discipline of environmental toxicology has advanced so that sensitive population responses to long-term exposure of chemicals, possibly below levels of analytical detection, can now be determined. We now have a very good understanding of our capabilities and our knowledge of environmental contaminants that can impact biological systems has expanded. Our computational knowledge and capability now possibly exceeds our ability to measure and detect chemical effects within the milieu of natural ecological variability. Artificial intelligence has also become one of the computational tools that is providing access to many more databases than were available previously.

Most important among the development of our skills and knowledge has been establishing ownership over the environmental management tools used in Canada. Canada developed its own water quality objectives, toxicity test and analytical methods that can be refined and modified as national and local needs required. Consequently, Canada became self sufficient and no longer relies on other countries or multi-national organizations like OECD or the International Organization for Standardization (ISO) to develop sufficiently flexible methods,

Figure 5: ATW/CEW Sponsors over the last 50 years.

as was the only option in the 1960s and 1970s. ATW/CEW has provided an important and functional forum to address national interests in the protection of aquatic ecosystems in a timely manner over the last 50 years.

ATW/CEW has been ahead of many other environmental organizations over the years. It formed three years before the Annual Symposium on Aquatic Toxicity of the American Society for Testing and Materials (ASTM), six years before the Society of Environmental Toxicity and Chemistry (SETAC), and did so without membership fees, significant administrative overhead, or a subsidy from established institutions. It was among the first conferences to create a web site and an online administration program, which was first established to help manage the 1997 workshop at Niagara Falls. ATW/CEW has managed largely on the volunteer efforts of environmental scientists, managers, academics and students across Canada. The creation of the continuity fund to support organizing committees and the student program has made the organization financially self-sustainable.

Sponsors and Supporters

ATW/CEW has stayed vibrant through the enthusiasm of organizing committees and the leadership of the Chairs, who represent the foundation of its longevity and success.

ATW/CEW has benefited from the long-term support of DFO and EC, both through the provision of staff time and direct funding. All the continuity Chairs have been from these two organizations.

ATW/CEW has also received monetary and staff resources from provincial governments, universities, consulting companies, and resource, manufacturing and service industries when the annual meeting has arrived in their respective regions. Everyone has participated and worked together to make each workshop a success. The logos of many of ATW's sponsors (Figure 5), some of which have been acquired or merged, provide an indication of the broad base of support over the years.

CHAPTER 4

Standardized Toxicity Methods for Regulatory Application: A Brief History and Future

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Canadian context – Pre-1990

Prior to 1990, there was limited application of aquatic toxicity testing in Canadian environmental regulation. Federally, the rainbow trout acute lethality test was the only toxicity test used as a compliance requirement under the Fisheries Act (FA) Pulp and Paper Liquid Effluent Regulation (PPLER) but only applying to pulp and paper mills built after 1971. All other Fisheries Act regulations suggested the use of toxicity testing under voluntary guidelines. In the provinces of Ontario, Quebec and British Columbia, there was some application of fish acute lethality in effluent permits or control orders where provincial test methods were used.

However, starting in the late 1970s, there was significant advances in Canadian toxicology method development and numerous presentations given at annual meetings of the Aquatic Toxicity Workshop (ATW) and the Society for Environmental Toxicology and Chemistry (SETAC). Unfortunately, the lack of standardized toxicity test methods and no laboratory accreditation program for biological testing held back the application of environmental toxicology in Canadian environmental regulations.

During this same time period, federal and provincial regulatory control limits for industrial and municipal effluent discharges were limited and very ineffective, relying on a small number of chemical-specific compliance limits across the different sectors. To illustrate this regulatory ineffectiveness, Figure 1a and 1b

Figure 1a: Final treated effluent discharge point at Mill A

Figure 1b: Final treated effluent discharge point at Mill B

show the final treated effluents after release from two Northern Ontario pulp mills in 1983. These effluents were acutely lethal to fish at concentrations ranging from 5% and 10%. However, these mills were in compliance with environmental discharge standards as they existed at that time.

Canadian context – Regulatory need for EC standardized biological test methods: The beginning

Fortunately, in early 1990, Conservative federal government launched a new environmental program known as “The Green Plan”. One of the many priorities under this program was the updating of the Pulp and Paper Effluent Regulation (PPER). Environment Canada (EC)[1]’s proposed update would require the rainbow trout acute lethality test as a compliance limit applying to all pulp and paper mills in Canada. To prepare for this significant new application of toxicity testing, Environment Canada toxicity experts and toxicologists from the provinces of Quebec, Ontario, Saskatchewan, Alberta and British Columbia worked together to prepare new national standardized acute lethality Reference Methods using rainbow trout & Daphnia magna for incorporation into the 1992 PPER as compliance & monitoring parameters, respectively.

Why are standardized test methods needed?

In late 1992, EC management in the Environmental Protection Service made the decision to create the Biological Methods Division[2] with a mandate to develop and standardize toxicity methods for better protection of Canadian waters, sediments and soils. Standardized methods ensure certainty and national consistency in their application regulatory application in pollution control across Canada. These methods provide a specific set of instructions and conditions to be used:

- in environmental regulations, permits and guidelines at both the federal and provincial level;
- in enforcement sample testing for regulatory auditing and General Provision of the Canadian Fisheries Act; and
- by private toxicology laboratories who provide testing services to industrial

[1]*When the Department of Environment was formed, the name “Environment Canada” was used. In 2015, the name was changed to “Environment and Climate Change Canada.”*

[2] *The Biological Methods Division grew over time, and the standardized methods program was later the responsibility of the Method Development and Applications Unit.*

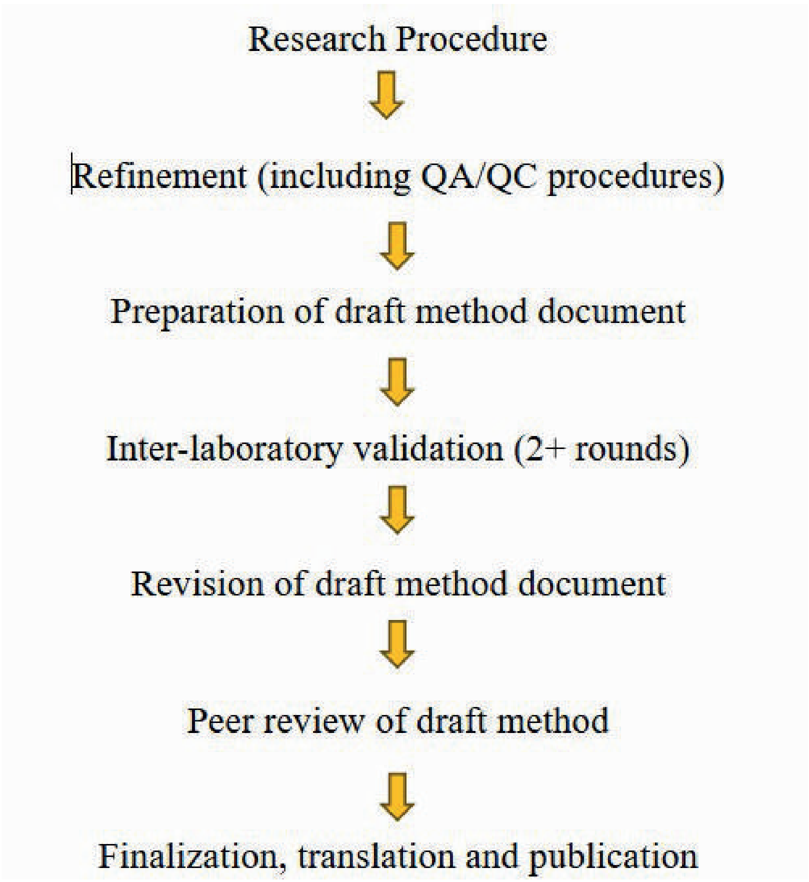


Figure 2: Steps followed by EC to prepare a standardized test method

and municipal clients for both regulatory and non-regulatory monitoring.

Figure 2 illustrates the steps to be followed to convert a research procedure into a standardized test method.

Focused method improvement research, inter-laboratory validation and peer review are the corner stones to EC's biological test method program[3]. Typically, 5 to 10 years is required to move from the method research stage to formal publication as an EC standardized biological test method. Over the past 35 years, focused method development and refinement research has involved many students and toxicologists from organizations covering government, academia, industry and consulting laboratories. Since the beginning of the standardized test method program, EC has published 28 standardized biological test method documents for conducting toxicological testing on priority substances and contaminant mixtures in water, sediment and soil. Another advancement is laboratory accreditation for Canadian toxicology laboratories. Accredited laboratories can seek accreditation for all EC standardized test methods.

Over the years, EC standardized toxicity test methods have been incorporated into three Fisheries Act regulations for acute lethality compliance and sublethal toxicity monitoring requirements under Environmental Effect Monitoring (EEM) provisions, into hundreds of provincial effluent regulations and discharge permits, two regulations under the Canadian Environmental Protection Act (CEPA), Canada-wide Standards (e.g. Petroleum Hydrocarbons in Soils) and are used to generate data for the derivation of environmental guidelines for water, sediment and soil.

Examples of method application in Canadian regulations

To illustrate how standardized toxicity tests are used in Canadian regulations, three examples of their application follow. The first case study is taken from the Fisheries Act PPER. Since 1992, the rainbow trout Reference Method (EPS 1/RM/13) has been successfully used in this regulation as a compliance limit across the entire sector. As regulatory amendments came into force, the acute lethality limit (i.e., greater than 50% trout survival in full strength effluent) required many pulp and paper mills across Canada to upgrade existing or build new effluent treatment systems to comply with the regulations. Over $500 million dollars was spent by the Canadian pulp and paper industry over a 20-year period to come into

[3]Biological test method program is used interchangeably with standardized toxicity test methods program.

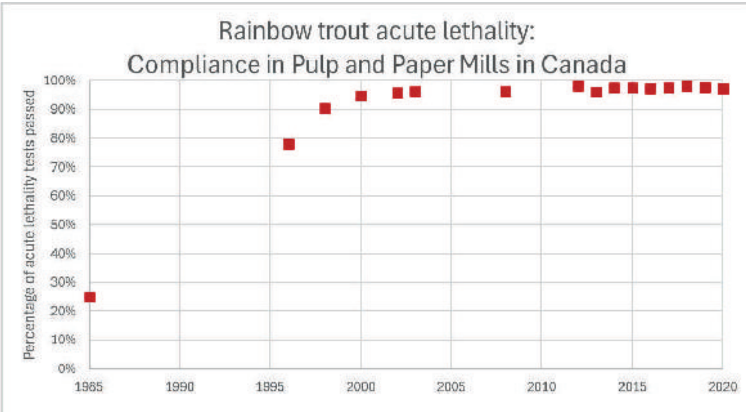


Figure 3: Annual final effluent compliance to rainbow trout acute lethality requirement by the Canadian pulp and paper mills[4].

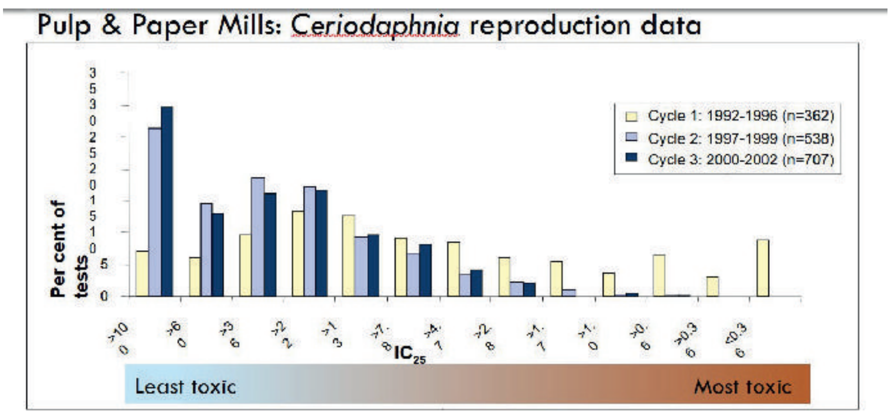


Figure 4: Improvement in Ceriodaphnia IC25 between EEM cycles 1 and 3.

[4]Sources (i) Environmental Indicators, Pulp and paper effluent quality website on ECCC's website. (ii) Status report on the Pulp and Paper Effluent Regulations. 2012. (iii) ECCC's Forest Products and Fisheries Act Division.

compliance to the rainbow trout acute lethality requirement. Figure 3 shows the significant reduction in final effluent acute lethality in final effluent over time.

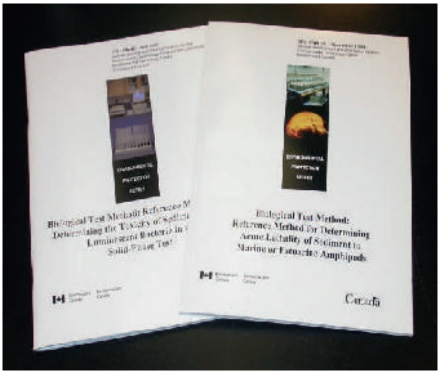
This significant improvement in effluent quality did not come easily. From 1996 to 1999, EC enforcement actions against regulated mills led to a number of out-of-court settlements and court cases which up-held the acute lethality provisions in the PPER. Also, testimony from court cases, feedback from toxicology lab accreditation assessors and issues identified by private lab toxicologists has led to further improvements to the defensibility of the rainbow trout acute lethality method (i.e., December 2000 publication of a second edition of the RM/13 method and four additional amendment sheets).

The second example is testing to monitor the quality of treated effluents under the Environmental Effects Monitoring component of the PPER. This regulation requires the regulated industry to test their final treated effluent using a suite of sublethal toxicity tests. One of the most effective tests for measuring the improvement in effluent quality over time has been the reproduction inhibition test using the invertebrate species, Ceriodaphnia dubia (i.e., EPS 1/RM/21). For the EEM program, this test generates results that allows the calculation of a statistical endpoint for estimating the Inhibition Concentration causing 25% (IC25) effect on organism reproduction when exposed to treated pulp & paper effluent. The IC25 test endpoint data illustrated in Figure 4 clearly shows a substantial improvement in effluent quality between EEM Cycle 1 (1992 to 1996) and Cycle 2 (1997 to 1999). This significant reduction in effluent sublethal toxicity reflects the industries' investment in improved effluent treatment across the sector between 1992 and 1996.

The third example is the application of a suite of EC marine sediment test methods in the CEPA Disposal at Sea regulation.

This regulation is the instrument used by Canada to meet international obligations under the London Dumping Convention regarding open water disposal of dredged sediments and wastes and is a permit-based program for regulating open water disposal decisions vs other waste management options. The regulation uses a combination of chemical action levels and pass/fail limits for sediment toxicity tests for permit decision making. Figure 5 lists the EC sediment toxicity test options for Tier 2 biological testing under the regulation.

For sediment disposal permit applications, data must be submitted to Environment Canada that characterizes the candidate sediments. Staff with EC's disposal at sea program will determine if the proponent should receive a permit to



Amphipod survival (Rhepoxynius abronius, Amphiporeia virginiana, Eohaustorius estuarius and E. washingtonianus), in Reference Method EPS 1/RM/35

Luminescent bacteria inhibition (Vibrio fischeri), in Reference Method EPS 1/RM/42

Echinoid embryo/larval inhibition (Lytechinus pictus, Strongylocentrotus purpuratus, Dendraster excentricus), in Reference Method STB 1/RM/58

Polychaete survival & growth (Polydora cornuta) in generic method EPS 1/RM/41

Figure 5: Suite of Sediment Toxicity Test Methods cited in the CEPA Disposal at Sea regulations

dredge and dispose of sediment at an approved open water disposal site. If the permit is not approved, the proponent will have to pursue another water management option (e.g., confirmed disposal, upland disposal, etc.) to deal with their waste sediment or other wastes. Permit decisions are based on clear action levels outline in the CEPA regulation.

Strong foundation of standardized toxicity test methods

When ECCC1's standardized toxicity test method program started, the focus was on freshwater aquatic methods, and over the next three decades, it has grown to include marine aquatic, sediment and soil methods using representative Canadian test species. It has grown not only in the environmental compartments which are covered, but also in the taxonomic groups that we aim to protect—the ECCC methods include vertebrates, invertebrates, plants and algae.

As outlined above, different regulatory programs of ECCC have incorporated these methods directly into Fisheries Act and CEPA regulations, setting a regulatory precedent for the direct use of toxicological methods in environmental protection at both the federal and provincial level. Both in the past and present, there has been an emphasis on laboratory accreditation and stringent quality assurance criteria. ECCC plans to continue their partnership with Canadian accreditation organizations, such as the Canadian Association for Laboratory Accreditation (CALA), to ensure high confidence in the robustness and repeatable of standardized toxicity test methods.

Opportunities in the future: Existing methods and new methods

Method development is not a one-time process. Like any scientific discipline, knowledge changes and grows over time. The biological test methods program will look to updating and refining methods over time, and co-ordinate that process with laboratory personnel, with accreditation bodies and with other standardization organizations.

Laboratory personnel, in both the private and the public sector, have significant expertise in the performance of standardized toxicity test methods. Laboratory-level learning continues long after methods are published, and by partnering with laboratory scientists, we can collectively gain knowledge which will improve the methods. ECCC's decades-long partnership with CALA ensures that methods continue to perform well over time. In addition, as ECCC staff are CALA assessors themselves, we can identify quality assurance issues which may be impacting more than one laboratory. Finally, experts assisting other standardization organizations, such as those operating under the auspices of ASTM, EPA and ISO and OECD, will continue to be essential collaborators, both for updating existing methods and developing new methods. There are many commonalities among standardization organizations, both in the species which are selected as model organisms, as well as in the steps used to standardize toxicity test methods. Because of those commonalities, ECCC's biological test methods program can gain significant efficiencies and avoid duplication of effort by building professional networks which extend into other standardization groups.

Opportunities in the future: Maintaining and expanding reach in application

As a scientific discipline, ecotoxicologists in Canada are innovative, responsive to the need to assess new contaminants and endlessly curious in mechanistic understanding. Conversations are evolving and growing as we learn, meet new challenges and think of new applications. Looking ahead, how can we ensure that standardized toxicity test methods are part of these conversations? Three examples follow, which illustrate possibilities for maintaining and expanding reach in application.

We can continue to keep confidence and awareness high among policy makers, regulators and stakeholders/rights holders by, for example, periodically reviewing data which result from the regulatory use of standardized toxicity test methods. This feedback loop in regulatory use is essential for keeping communication channels open and relevance of ecotoxicology high.

Many researchers in academia are already aware of standardized toxicity test methods. If there is alignment with their research goals, colleagues in academia may already use standardized toxicity test methods as a starting point for research, a practice which will likely continue in the future. For example, culturing techniques and biological endpoints from ECCC methods can be used as-is or slight modification to meet a specific research objective. There are possibilities for more expansive thinking here too. For example, researchers could consider applying some quality assurance steps, to confirm the robustness of their data.

There is a tendency for aquatic receptors to be a focal point in ecotoxicology, perhaps because of its longer history and clear regulatory links with industrial effluent monitoring and control. Soil toxicology methods have been developed and standardized by ECCC's biological methods program, and have potential to be more-broadly used in a regulatory context, if and when those regulatory contexts emerge. In Europe, for example, there is a stronger environmental protection framework for soils which, among other things, has led to more application of soil toxicity test methods. Our soil toxicity methods have already been used in regulatory applications in Canada (Canada Wide Standard for Petroleum Hydrocarbons in Soil), and this has lead to gains in environmental protection for surface soils.

Future directions of growth

The idea of directions of growth can be used to describe how the standardized methods program will integrate innovation into our future work and build on current momentum-gaining science. The technology advancements (e.g., omic measurement techniques, gene sequencing) of today will be carried forward into the future new or revised test methods. This future will also incorporate animal alternative advances

Ecotoxicologists in Canada and globally are constantly developing new technologies, such as toxicogenomic tools, and challenging the scientific community to consider new biological endpoints. Collaborations here can help both regulators and researchers, as regulators can see the opportunity to incorporate the latest science into policy, and researchers can have the benefit of seeing the policy impacts of their research. In this context, parallel testing—where new rapid measurement techniques and test systems are carried out side-by-side with standardized toxicity test methods—can help advance the use of these new tools.

In Canada and abroad, the reduction in the use of vertebrates in testing has evolved, driven by a moral imperative. The 3Rs (replacement, reduction, refinement) has and will continue to be a focal point. ECCC's biological test methods program has already taken significant steps, including incorporating control sharing into the rainbow trout acute lethality method, and incorporating the 3Rs in the development of the recently-published amphibian test method. In the future, we plan to build on existing momentum to further government-wide initiatives in adopting the 3Rs.

ECCC has always been the "home base" for standardized toxicity test methods, and federal public servants in Canada benefit from a strong connection with values and ethics. Diversity, equity and inclusive (DEI) is one of the recent, and most powerful, directions in values and ethics across the Canadian federal government. Being a champion in DEI has amplified the government's commitment to achieve a workplace culture where everyone is included and valued. DEI will influence our science work in many ways in the future. Certainty, there will be a seat at the table for Indigenous rights holders in the development of environmental regulations, and an impactful example which is underway today is the involvement of the Crown-Indigenous Working Group in the development of a potential Oil Sands Mining Effluent Regulation. For those future days when the standardized methods program is invited into a leadership role, these will undoubtably be opportunities for us to put EDI into action, whether it be through celebrating International Day of Women and Girls in Science, activities to mark National Day for Truth and Reconciliation, or simply ensuring the diversity in the Canadian population is mirrored in our team selection. Lastly, there are small steps we can continue to take to check that our science content is accessible to all, by working with web communications teams to make science content available to the public through technology assistance and by ensuring that posters and presentations have high-contrast text and backgrounds.

Critical maintenance

In addition to the growth paradigm, we need to remain focused on critical maintenance to ensure our foundations in regulatory method application remain stable. Activities such as maintaining professional networks, monitoring QA/QC and science communication will continue to support sound regulatory test methods, and help ensure a strong foundation in the coming decades.

The biological test methods program has benefited tremendously from many scientists in our professional networks. Consulting and private labs deserve particular recognition here, as their expertise has often gone under the radar, perhaps because they tend not to publish as often as colleagues in academia. Scientists in consulting and private labs have decades of experience, both in performing the tests and in interpreting the results. Continued partnerships with Co-op programs at universities and other academic affiliations will help train future ecotoxicologists, and our program in turn gains from their fresh perspectives.

CHAPTER 5

The Evolution and Application of Microbiotests in Aquatic Toxicology

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Introduction

"The dose makes the poison" - Paracelsus (1538)

Awareness of environmental pollution and its impact on aquatic ecosystems has increased exponentially since the mid-20th century. The field of aquatic toxicology has evolved significantly during this period, leading to the development of standardized toxicity tests for environmental monitoring. While early work focused on fish (Sprague, 1969), a keystone taxonomic group in the aquatic environment, with links to human health (due to human consumption of fish), interest necessarily grew to lower trophic levels, upon which fish and fish habitat health rely. Major milestones in the history of aquatic toxicology are highlighted in Table 1.

Standard Aquatic Toxicity Tests

Traditional aquatic toxicity tests involve a range of organisms representing trophic levels in aquatic (both freshwater and marine) ecosystems:

- aquatic plants:
  - freshwater: green algae (*Pseudokirchneriella subcapitata*), duckweed (*Lemna minor*)
  - marine: diatom (*Skeletonema costatum*), red algae (*Champia parvula*)
- invertebrates:
  - freshwater: daphnids (*Daphnia magna*), amphipods (*Hyalella azteca*)
  - marine: sea urchins (*Lytechinus pictus*), copepods (*Tisbe battagliai*), mysids (*Mysidopsis bahia*)

Table 1: Historical development in aquatic toxicology from the 1950s to present.

Decade	Advances
1950s	The field of ecotoxicology emerged, but assessment techniques were inadequate
1960s	Fish bioassays were developed and standardized, to confirm potential impact of industrial effluents on aquatic environments
1970s	Governments established environmental agencies, such as the U.S. Environmental Protection Agency (EPA), to regulate pollution; Early test methods focus on acute toxicity
1980s	Holistic approaches integrating biological and chemical strategies emerged Emergence and publication of validated test methods (ASTM, USEPA, Environment Canada), with a focus on sub-lethal toxicity
1990s	Research on microscale toxicity tests (and development into test kits) progressed, with an aim to improve environmental monitoring, in particular, in real-time scenarios (e.g., spills)
2000s	Advancements in toxicity tests enhanced efficiency and applicability
Present and beyond	Increased use of biomarkers, enzymes and other biochemical indicators (See Simmons, 2025; Chapter 6)

- fish:
  - freshwater: rainbow trout (*Oncorhynchus mykiss*), fathead minnow (*Pimephales promelas*)
  - marine: inland silverside (*Menidia beryllina*), threespine stickleback (*Gasterosteus aculeatus*)

These tests require laboratory infrastructure, technical expertise, and time (>2 days), making them – in some cases - expensive and logistically challenging.

Microbiotests: Concept and Development

Microbiotests began developing during the 1990's to provide faster, simpler, and more focused aquatic toxicity assessments. The ability to circumvent or optimize the culturing of various aquatic organisms such as daphnids, rotifers, ostracods, protozoans, algae and bacteria into a stable form (e.g., cysts, beads and lyophilized forms) that allows for ease of shipping and handling, has facilitated the development of microbiotests as rapid toxicity assessment tools. The ability to incorporate the implementation of microbiotests into mobile environmental laboratories (some of which were already being used for analytical chemistry) or their direct use in the field, facilitated better options to support research, monitoring and regulatory applications.

Microbiotests use microorganisms or early life stages of macrofauna, allowing for: rapid evaluation of the effects of chemicals or contaminant mixtures (Blaise, 1998a); assessment of multiple matrices (water, soil, sediment) (Blaise *et al.*., 1998b); and, reliable and cost-effective monitoring. Initially, microbiotests focused on bacterial and protozoan assays for water quality monitoring (Cairns & Niederlehner, 1995); however, they began to expand into higher trophic levels, but were still able to maintain a small-scale format. Since the late 1990s and early 2000s, the applications of microbiotests have expanded to various environmental matrices and pollutants.

Key milestones in the history of the development and application of microbiotests are as follows:

- bacterial assays were first used for water toxicity screening (Cairns & Niederlehner, 1995);
- algal and protozoan assays extended the approach to soil and sediment assessment (Blaise *et al.*., 1998b);
- acute and chronic toxicity tests allowed for short- and long-term chemical impact evaluations; and,
- inclusion of microbiotests for environmental applications to monitor for DNA damage (i.e., genotoxicity and mutagenicity) (Houk, 1991).

Table 2: Comparison of characteristics of traditional toxicity tests vs. microbiotests

Characteristic	**Traditional toxicity tests**	**Microbiotests**	**Reference**
Affordability	due to infrastructure, technical expertise and culturing, cost per sample can be relatively high	low cost/sample enables widespread use, and the capacity for increasing sample size (which increases confidence in the data)	Blaise *et al.*, 2000
Test organisms	culturing often requires technical expertise, facilities and time	many tests utilize dormant stages that can be activated by adding water	
Throughput	relatively lower throughput, due to cost, time and logistical considerations	multiple samples can be processed concurrently and efficiently	Weltje *et al.*, 2013
Speed of obtaining results	in the realm of a week	rapid, crucial for real-time decision-making in environmental emergencies (e.g., spills)	Farre *et al.*, 2004
Field applicability	N/A	miniaturized, portable test kits facilitate on-site testing	
Repeatability (quality control)	higher standard deviation from lab cultures during inter-laboratory comparisons.	improved standard deviation (Figure 1, below)	Persoone *et al.*, 2009
Holding times	shipping delays or long transit times may impact the samples before they arrive at the laboratory	testing in-house or on-site eliminates issues with shipping delays and results are immediate.	Thapa et al., 2020

Microbiotests have been introduced and incorporated into a variety of environmental risk and impact assessment programs. For example, in industrial discharge monitoring they have been used in assessing effluent toxicity (Blaise *et al.*., 2000). Moreover, the have been used in evaluations of chemical spills to measure toxicity subsequent to a spill (Farre *et al.*., 2004). In contaminated site assessments, they have been used to evaluate soil and sediment toxicity to understand if elevated concentrations of one or more chemicals of concern may result in significant biological effects/impacts (Kwan & Dutka, 1995). When analyzing agricultural runoff, they have been used to monitor pesticide and fertilizer impacts in real time (Weltje *et al.*., 2013). Finally, some regulatory agencies have incorporated microbiotests in compliance monitoring.

Early in this century, focus on effects at the sub-chronic DNA level (i.e., genotoxicity/mutagenicity) resulted in new ISO guidance for mutagenicity and genotoxicity determination in water (Ames fluctuation test; ISO, 2012; umu-test; ISO, 2000) included to assist with “genotoxicity backtracking". The latter concept has been successfully applied to both drinking water for: the detection of mutagenicity in disinfectant by-products; and, the detection of genotoxicity of single substances in river waters (OSPAR Commission, 2002).

Microbiotests: Advantages

Microbiotests have significant advantages over traditional toxicity test methods, as outlined in Table 2.

Microbiotests: Example Case Studies

Technological improvements have further enhanced microbiotests, specifically: high-throughput screening has increased efficiency (Weltje *et al.*, 2013); improved sensitivity allows for the detection of lower contaminant levels (Blaise, 1998); and, advanced data analysis tools aid in result interpretation (Cairns & Niederlehner, 1995).

The Role of Test Kits in Environmental Assessment

Microbiotests significantly contribute to:

- regulatory frameworks – some environmental agencies have incorporated microbiotests into pollution assessment/control programs (OECD, 2013);
- scientific research – microbiotests provide a robust basis for ecotoxicological studies (Blaise *et al*., 1999);
- industry compliance – Companies use microbiotests to meet environmental standards (microbiotests.com; ebpi.com); and,
- guidance documents are currently being reviewed, tested and implemented

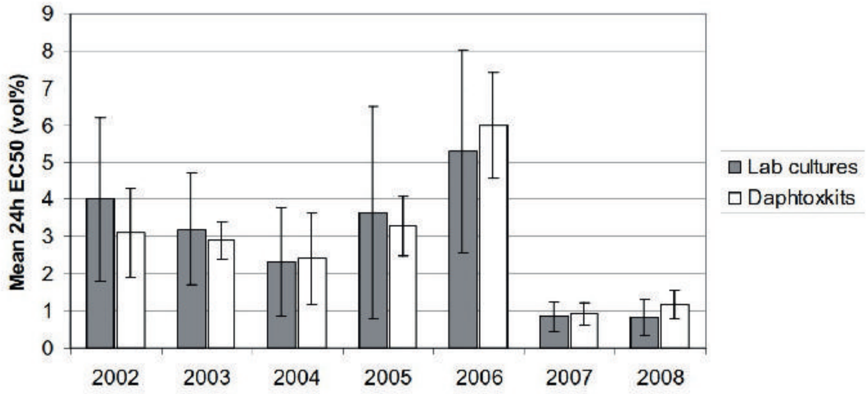

Figure 1:Mean 24-hr EC50s (in mg/L; with standard error bars) for quality control tests with potassium dichromate, representing lab culture tests vs microbiotests for Daphnia magna (from Persoone et al., 2009).

internationally (ISO, 2012, 2000) for monitoring of water quality for genotoxicity and mutagenicity globally (Rao and Rokosh, 2000).

There are many validated test kits that are used for environmental monitoring and risk assessment. The ability to incorporate a battery of low-cost toxicity tests to help understand the potential biological effects of a site should be incorporated to allow for a better understanding of the environmental impact from the molecular/cellular level up to organism and species, to help predict any potential shifts in population and community structure.

The Role of Test Kits in Education

Over the last decade, EBPI (Canada) has modified protocols and kits to allow young environmentalists to incorporate these assays into their classroom settings from high school throughout university and college. By modifying the protocols of the tests, students can conduct tests per ISO, OECD, ASTM methods or research analysis for individual research projects or laboratory classroom use. The importance of allowing future scientists/researchers assess at an early stage to regulatory tests will allow for a better understanding of the importance of toxicity evaluation throughout their professional careers.

Conclusion

Microbiotests have evolved into an indispensable trusted tool in environmental monitoring and research in over 45 countries. Their affordability, efficiency, and adaptability make them essential for assessing environmental toxicity in aquatic, terrestrial and aerial environments With on-going technological advancements, these assays will continue to play a vital role in ecotoxicity studies and regulatory compliance now and in the future to assist in evaluating emerging chemicals of concern.

References

ASTM. 2013. Standard Guide for Conducting Acute Toxicity Tests with Fishes, Macroinvertebrates, and Amphibians. ASTM International.

Blaise, C, *et al.*. 2000. Application of Microbiotests for Environmental Risk Assessment. Water Research, 34(12), 3003-3012.

Blaise, C. 1998. Microbiotesting: An Expanding Field in Aquatic Toxicology. Ecotoxicology and Environmental Safety 40 (1-2): 115-119.

Blaise C, Wells P, Lee K. 1998b. Microscale testing in aquatic toxicology: introduction, historical perspective, and context. In: Wells P, Lee K, Blaise C

Table 3: Case studies illustrating the use and effectiveness of microbiotests

Case Study	Tests	Evaluation	Impact
Assessment of Water Quality in European Rivers Farre *et al.*, 2004	*Daphnia magna* *Vibrio fischeri* bioluminescence test (Microtox)	industrial and agricultural activities – impact to rivers	• led to the implementation of stricter wastewater treatment regulations • targeted remediation efforts in the most polluted river sections.
Monitoring the Impact of Marine Oil Spills Weltje *et al.*, 2013	algal growth inhibition tests *Pseudokirchneriella subcapitata* marine copepod tests (*Tisbe battagliai*) marine rotifer* (*Brachionus plicatilis*) UMU-ChromoTest Muta-ChromoPlate (Ames Test)	marine oil spills	• provided critical data for post-spill assessments • supported decisions on clean-up strategies and environmental restoration efforts. • during the Gulf of Mexico Oil Spill, the EPA mandated that the marine rotifer test be used to monitor levels of toxicity when dispersants were used. • hundreds of mandated Rotifer toxicity test were conducted on the research vessel GEOEXPLOER to understand the oil dispersant mixture effects. • genotoxicity and mutagenicity tests were used to detect levels of genotoxic/ mutagenic activity at both the Deepwater Horizon and surrounding beaches, suggesting that the inclusion of chronic assays be included.
Monitoring of Olive Mill Wastewater (OMW) Rouvalis *et al.*, 2004	Thamnotoxkit F and Daphtoxkit F pulex	acute toxicity of OMWs (traditional and continuous processes)	• detected significant correlation between the two microbiotests • compared the sensitivity of both toxkits, which was found to be higher for Daphtoxkit F. • accurate routine biomonitoring of OMW toxicity the use of both toxkits can be suggested.
Monitoring of Industrial Wastewater Discharge 1.Hendricks & du Preez, 2024 2.Guan *et al.*2017 2017 2017	1. umu-test/umu-ChromoTest (ISO, 2000) 2. Ames fluctuation test (ISO, 2012)	1. monitoring of treated water effluent / chemical manufacturing discharge. 2. monitoring of treated water effluent and polished waters.	1. lowering the potential of oxidative species being released into the environment. 2. monitoring and potential removal of mutagens during water treatment.

(eds) Microscale testing in aquatic toxicology: advances, techniques and practice. CRC Lewis Press, Boca Raton, pp 1–9.

Cairns, J, Niederlehner, B. 1995. Ecological Toxicity Testing. Lewis Publishers.

Guan, Y, Wang, X, Wong, M, Sun, G, An, T, Zhang G. 2017. Evaluation of genotoxic and mutagenic activity of organic extracts from drinking water sources. PLOS ONE 12 (1): e017454.

Farre M, Arranz F, Ribo J, Barcelo, D. 2004. Interlaboratory study of the bioluminescence inhibition tests for rapid wastewater toxicity assessment. Talanta. 62(3): 549-558.

Hendricks R, Du Preez, HH. 2024. Assessing the genotoxic potential of wastewater effluents from three wastewater treatment plants in South Africa. J Water Health. 22(2): 278-289.

Houk VS.1991. The genotoxicity of industrial wastes and effluents. Mutation Research/Reviews in Genetic Toxicology 277 (2): 91-138.

ISO, 2012. 11350 2012-05-15 Water quality — Determination of the genotoxicity of water and waste water — Salmonella/microsome fluctuation test (Ames fluctuation test).

ISO, 2000. 13829:2000 Water quality — Determination of the genotoxicity of water and waste water using the umu-test.

Kwan KK, Dutka BJ. 1995. Use of Bacterial Bioassays for Screening Contaminated Sediments. Journal of Environmental Science and Health, 30(6), 1345-1360.

OECD. 2004. Guidelines for the Testing of Chemicals. Organization for Economic Co-operation and Development.

OSPAR Commission. 2002. Survey on Genotoxicity Test Methods for the Evaluation of Waste Water within Whole Effluent Assessment. 42 pp.

Persoone G, Baudo R, Cotman M, Blaise C, Thompson, KCL, Moreira-Santos M, Volla B, Törökne A, Han T. 2009. Review on the acute Daphnia magna toxicity test – Evaluation of the sensitivity and the precision of assays performed with organisms from laboratory cultures or hatched from dormant eggs. Knowledge and Management of Aquatic Ecosystems, 393, 29 pp.

Rao, SS, Rokosh, DA. 2000. Environmental Genotoxins - Their Implications in Ecosystem Health: Current Use and Future Needs for Mutagenicity/ Genotoxicity Assays in Ecosystem Health Studies. NWRI Contribution No. 00-151

Rouvalis, A, Iliopoulou-Georgudaki, J, Lyberatos, G. 2004. Application of two microbiotests for acute toxicity evaluation of olive mill wastewaters. Fresenius Environmental Bulletin. 13 (5): 463-469.

Simmons, D. 2025. Future perspectives on “omics” approaches in ecotoxicology. In: Firty years of CEW 1974-2024. Eds. G. Craig and R. Scroggins, 93-106. The Canadian National Aquatic Toxicity Workshop Dartmouth, Nova Scotia, Canada .

Sprague, JB. 1969. Measurement of Pollutant Toxicity to Fish. Water Research, 3(11): 793-821.

Thapa, S, Stoodley S, Farnsworth-Hobeck K, Dzialowski A. 2020. Review on Effects of Holding Time Exceedances on Ambient Water Quality. Review on effects of holding time exceedances on ambient water quality. Proc. Okla. Acad. Sci. 100:102–111.

Weltje L, Wheeler JR, Weyers A, Galay-Burgos, M. 2013. Refinement of the ECETOC approach to identify endocrine disrupting properties of chemicals in ecotoxicology. Toxicol Lett 223 (3): 291-294.

CHAPTER 6

Future perspectives on "Omics" approaches in ecotoxicology

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Introduction to Omics

To understand omics approaches in toxicology, it is necessary to understand the central dogma of molecular biology and to define the biomolecules involved. The central dogma outlines the flow of information from gene to proteins in cells. It states that information flows from DNA to RNA, and then to protein, though it can also flow from RNA directly to protein. This flow is the basis for gene expression, where DNA is transcribed into RNA, which is then translated into proteins. In essence, the central dogma is a framework for understanding how DNA instructions are translated into functional proteins, forming the basis of gene expression and cellular function. Proteins perform many functions, including catalyzing metabolic reactions, DNA replication, responding to stimuli, as structural components in cells and organisms, and transporting molecules from one location to another. The small molecules in cells and organisms that proteins interact with are generally termed metabolites, and they provide energy, are the subunits of larger molecules, are used for signaling, markers, and tags for inter- and intra-cellular communication. Metabolites fall into many different classes, but broadly include sugars, amino acids and biogenic amines, nucleotides, and lipids. Thus, while the central dogma is a powerful model, it doesn't encompass all aspects of genetic information flow or molecular interaction. Figure 1 visually depicts the central dogma, including the additional downstream molecular interactions and some of the new paradigm that includes back and forth flow of information.

To conceptualize "omics" as an extension of molecular biology, I like to use this analogy: "a single invoice is to economics as a single gene is to genomics"

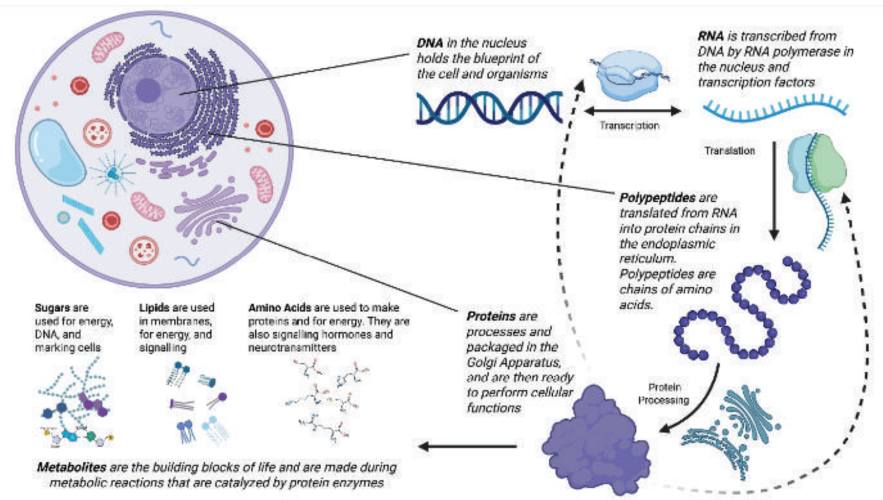

Figure 1: Visualization of the Central Dogma with new paradigm complexity. Created by D. Simmons in BioRender. Omicslab, A. (2025) https://BioRender.com/kc7a3z6

(see figure 2). Just as a single invoice provides insight into the economic activities of a business, a single gene can provide insight into the genetic makeup of an organism. However, just as a single invoice doesn't tell the whole economic story, a single gene doesn't fully explain the complexity of genomics. Both are pieces of a much larger puzzle that require a broader perspective to fully understand. Thus, my definition of “omics” is the application of innovative molecular tools that enable the identification and measurement of a very large number of molecules at once. The ultimate goal would be to measure every single biological molecule in a single sample, but in practice we are currently unable to do this. Thus, the discerning feature of conducting any “omics”, is the high-throughput measurement of hundreds to thousands of at once.

Recent advancements in omics technologies have revolutionized the field of ecotoxicology by providing detailed molecular insights into toxicant effects. Omics tools encompass various high-throughput techniques such as genomics, transcriptomics, proteomics, and metabolomics. In genomics, DNA is sequenced to identify species, genetic variations, and susceptibilities. Transcriptomics examines the expression of RNA transcripts to understand changes in response to an organism’s environment. Proteomics studies the entire set of proteins expressed, revealing alterations in protein abundance or modifications that can reflect responses to the environment and adaptations to stress. Metabolomics focuses on small molecule metabolites, reflecting alterations in biochemical and signaling pathways. These technologies typically utilize sophisticated platforms like next-generation sequencing and mass spectrometry, enabling rapid, large-scale (high-throughput) data generation.

The use of non-targeted omics approaches, such as untargeted metabolomics and transcriptomics, can significantly reduce bias in environmental effects monitoring and risk assessment. Traditional targeted approaches often focus on a priori-defined sets of chemicals or biological pathways, which can lead to biased or incomplete understanding of environmental effects. To illustrate this idea further, figure 3 displays "the blind men and an elephant" that shows how scientists can be susceptible to bias when only observing a subset of targets in a much larger, complex system. In contrast, non-targeted omics approaches provide a more comprehensive and unbiased view of the biological responses to environmental stressors, allowing for the identification of novel biomarkers and modes of action . By reducing bias and providing a more comprehensive understanding of environmental effects, non-targeted omics approaches can

Figure 2.: An analogy to understand the field of genomics.

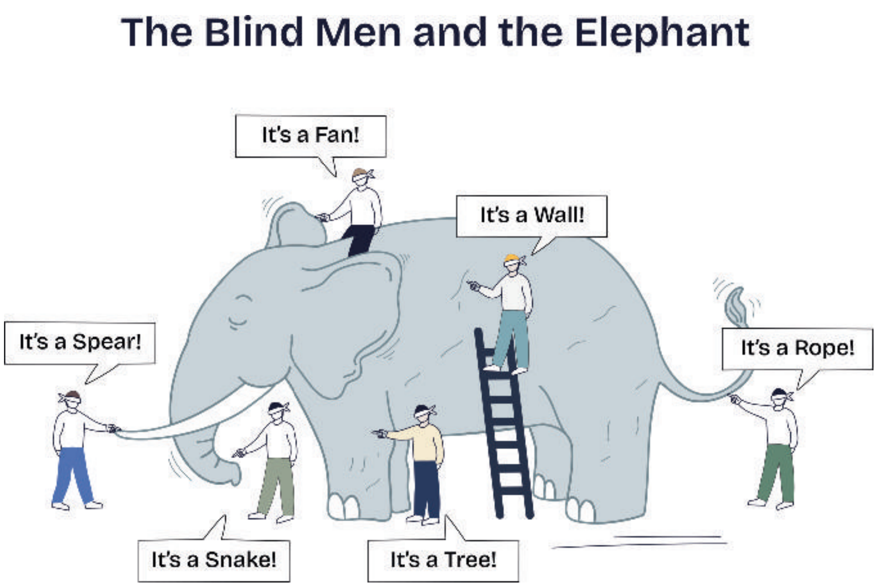

Figure 3: The Blind Men and the Elephant :by permision, created in BioRender. Omicslab, A. (2025) .
ID 379918120 | Elephant Blind Men © VectorMine | Dreamstime.com

improve the accuracy and effectiveness of environmental risk management (Martyniuk 2018, Madeira and Costa 2021). Additionally, non-targeted approaches facilitate the identification of new biomarkers—biological indicators of exposure, effect, or susceptibility—that can be used for early detection of toxic effects . The non-biased acquisition of data can help elucidate mechanisms of toxicity, providing insights that traditional testing methods may overlook.

How omics works

Omics became more mainstream in biological sciences since the turn of the millennia, due primarily to 3 innovations that have enabled high-throughput measurement and sequencing of large biomolecules: (1) next-generation (gene) sequencing; (2) Soft-ionization high-resolution tandem-mass spectrometry; and (3) high performance computer processing.

Next-generation sequencing (NGS) is a high-throughput method that allows for the rapid sequencing of entire genomes or targeted regions of DNA and RNA, enabling comprehensive genetic analysis. The process involves fragmenting genetic material into smaller pieces, attaching molecular adapters to these fragments, immobilizing the adapters on a solid surface, and then sequencing them with nucleotide incorporation using techniques such as bridge amplification or emulsion PCR . As nucleotides are incorporated, they are detected in real-time using methods like fluorescently labeled reversible terminators (Bentley, Balasubramanian et al. 2008). This technology facilitates parallel sequencing of millions of gene fragments simultaneously, providing detailed insights into genetic variations, mutations, and gene expression patterns, significantly increasing speed and reducing costs compared to traditional Sanger sequencing . NGS has revolutionized genomics research for molecular research in wildlife and non-model organisms due to its speed, accuracy, and cost-effectiveness.

Liquid chromatography high-resolution tandem mass spectrometry (LC-HR-MS/MS) is a powerful analytical technique widely used for the identification and sequencing of proteins. In this approach, complex protein mixtures are first digested into smaller peptides, typically using enzymes such as trypsin . These peptides are then separated by liquid chromatography based on their physical and chemical properties, such as hydrophobicity. As the peptides elute from the chromatography column, they are ionized, usually by soft-ionization such as electrospray ionization, and introduced into the mass spectrometer. The first stage of MS (MS1) measures the exact mass-to-charge ratios (m/z) of the intact peptides, and then selected peptides from MS1 are then fragmented in the collision cell, producing MS/MS spectra that are measured in the second stage (MS2) that contain sequence-specific fragment ions . These spectra are analyzed using bioinformatics algorithms to determine peptide sequences, which are subsequently mapped back to known proteins sequences obtained from public sequence databases . LC-HR-MS/MS thus enables detailed protein identification based upon amino acid sequence, and insights into post-translational modifications, making it an essential tool in proteomics research. This technique has revolutionized proteomics, enabling high-throughput protein sequencing and quantification .

Metabolomics instruments are usually based upon chromatography (gas or liquid) to separate the small molecules and then mass spectrometry (MS) or nuclear magnetic resonance (NMR) for detection. Both targeted and non-targeted methods are common (Viant, Ebbels et al. 2019, Olesti, González-Ruiz et al. 2021). One attractive benefit of metabolites is that they do not vary due to genetic sequence, and therefore the methods are more transferable across species and biological taxa. Additionally, one can argue that the ultimate product of a gene, and therefore the phenotype of an organism, will be realized at the protein and metabolite levels. Therefore, multi-omic approaches are likely to provide the most complete and reliable picture for understanding complex environmental impacts of chemical and stressors on organisms, populations, and ecosystems – because we can truly understand adverse outcomes at multiple levels of organization.

Advancements in computer processing speed have significantly transformed omics by enabling the development of faster instruments and more sophisticated bioinformatics analyses . High-performance computing allows for the rapid handling and processing of large-scale omic data generated by next-generation sequencing platforms and mass spectrometers, reducing analysis time from weeks to hours . Faster processors and increased computational power facilitate real-time data processing, improved accuracy in sequence assembly/de novo sequencing, database search, and more efficient variant detection. Additionally, advancements in bioinformatics algorithms and software tools leverage these computational improvements to statistically analyze complex datasets, leading to more precise insights and accelerating applications in ecotoxicology (Cox and Mann 2011, Mardis 2017). Overall, the synergy between improved computational speed and innovative bioinformatics has been pivotal in making omics more accessible and impactful to environmental researchers.

Large targeted panel assays containing hundreds of biomarker genes/proteins/ metabolites will likely become the mainstay for toxicological screening in the near future. These assays must be based upon data collected first form the non-targeted omics approaches so that they are developed with reduced-bias and confidence . The EcotoxChip, a Canadian innovation, is an example of a targeted high-throughput RNA assay. EcotoxChip is a microarray-based tool that enables simultaneous analysis of multiple biomarkers and pathways involved in toxicity processes, providing comprehensive insights into chemical impacts on aquatic and terrestrial organisms . Its capacity to detect gene expression changes related to stress response, detoxification, and developmental disruption makes it a valuable asset for environmental risk assessment. Overall, EcotoxChip's capabilities significantly advance the predictive power of environmental toxicology, linking molecular-level responses to ecological health outcomes in more than one species . We are sure to see this tool used more extensively at future Canadian Ecotoxicity Workshops as a mainstay for ecotoxicological risk assessments.

Current applications of omics in ecotoxicology and future perspectives

The integration of omics approaches, such as transcriptomics, proteomics, and metabolomics, has revolutionized the field of environmental toxicology by providing a comprehensive understanding of the molecular mechanisms underlying toxic responses. Omics approaches can identify changes in gene expression, protein abundance, and metabolite levels associated with exposure to environmental stressors, allowing for the elucidation of molecular mechanisms of toxicity (Martyniuk 2018, Shi, Cheng et al. 2024). These molecular mechanisms can be linked to adverse outcome pathways (AOPs), which are conceptual frameworks that describe the sequential events leading from molecular perturbations to adverse outcomes at the individual or population level (Ankley, Bennett et al. 2010, Villeneuve, Crump et al. 2014, Knapen, Angrish et al. 2018). By understanding the molecular mechanisms underlying adverse effects, researchers can develop more targeted and effective strategies for mitigating the impacts of environmental pollutants on human health and the environment.

Transcriptomic points of departure (tPODs) are increasingly being used to assess the potential adverse effects of chemicals on organisms (Olesti, González-Ruiz et al. 2021, Costa, Johnson et al. 2024) . Cell culture and embryo assays are popular in vitro models for toxicity testing, and transcriptomic analysis of these systems can provide valuable insights into the molecular mechanisms of toxicity . Increasingly, zebrafish embryo assays are also being used for this kind of assessment (Wang, Xia et al. 2020, Gou, Ma et al. 2023, Min, Lee et al. 2023), and these assays are considered a reduction in the use of animals for research. The use of transcriptomic PODs in ecotoxicology has several advantages, including the ability to detect subtle changes in gene expression and to identify potential modes of action (MoA) of toxicants in AOPs . According to the OECD, transcriptomic data can be used to support the development of adverse outcome pathways (AOPs) and to derive PODs for risk assessment (Harrill, Viant et al. 2021). Overall, the use of transcriptomic PODs in cell culture and embryo assays has the potential to improve the accuracy and efficiency of ecotoxicity testing and risk assessment, as well as reducing the use of animals in research.

The use of non-lethal sampling and omics technologies has improved Environmental Effects Monitoring (EEM) by providing a more comprehensive and mechanistically informed understanding of environmental pollution, while minimizing the impact on wildlife populations. Non-lethal sampling methods, such as blood sampling, skin mucus collection, and fin clipping, can be used to collect biological samples from living organisms, allowing for the assessment of molecular responses to environmental stressors. Omics technologies, including transcriptomics, proteomics, and metabolomics, can then be applied to these samples to identify biomarkers of exposure and effect (Valavanidis, Vlahogianni et al. 2006, Nesatyy and Suter 2007, Gallego-Ríos, Peñuela et al. 2021, Portugal, Mansilla et al. 2022, Sun, Fang et al. 2022). The use of non-lethal sampling and omics in EEM offers several advantages, including reduced animal mortality, increased sampling efficiency, and improved data quality . By integrating non-lethal sampling and omics, researchers can gain a better understanding of the effects of environmental pollutants on wildlife populations and develop more effective strategies for environmental risk management.

Looking ahead, the future of omics in environmental toxicology lies in integrative multi-omics strategies, combining genomics, proteomics, and metabolomics to provide a holistic view of biological responses (Ebner 2021, Shi, Cheng et al. 2024). These approaches can enhance environmental risk assessments and support the development of targeted remediation strategies and for the development of greener chemistries (Osman, Zhang et al. 2024, Ghasemlou, Nguyen et al. 2025). The future might incorporate more AI into hazard assessment and screening, and non-targeted omics data can aid in creating rich datasets for training such models for accurate in silico assessments . Furthermore, integrating omics data into regulatory frameworks can improve pollutant monitoring and policy decisions, promoting healthier ecosystems and communities. In conclusion, omics tools have substantially advanced environmental toxicology by enabling detailed molecular investigation of pollutant effects. By enhancing our understanding of toxic mechanisms and facilitating early detection, these technologies are vital for protecting environmental and human health in an increasingly polluted world.

References

Aebersold, R. and M. Mann (2003). "Mass spectrometry-based proteomics." Nature 422(6928): 198-207.

Ankley, G. T., R. S. Bennett, R. J. Erickson, D. J. Hoff, M. W. Hornung, R. D. Johnson, D. R. Mount, J. W. Nichols, C. L. Russom, P. K. Schmieder, J. A. Serrrano, J. E. Tietge and D. L. Villeneuve (2010). "ADVERSE OUTCOME PATHWAYS: A CONCEPTUAL FRAMEWORK TO SUPPORT ECOTOXICOLOGY RESEARCH AND RISK ASSESSMENT." Environmental Toxicology and Chemistry 29(3): 730-741.

Basu, N., D. Crump, J. Head, G. Hickey, N. Hogan, S. Maguire, J. G. Xia and M. Hecker (2019). "EcoToxChip: A next-generation toxicogenomics tool for chemical prioritization and environmental management." Environmental Toxicology and Chemistry 38(2): 279-288.

Bentley, D. R., S. Balasubramanian, H. P. Swerdlow, G. P. Smith, J. Milton, C. G. Brown, K. P. Hall, D. J. Evers, C. L. Barnes, H. R. Bignell, J. M. Boutell, J. Bryant, R. J. Carter, R. K. Cheetham, A. J. Cox, D. J. Ellis, M. R. Flatbush, N. A. Gormley, S. J. Humphray, L. J. Irving, M. S. Karbelashvili, S. M. Kirk, H. Li, X. H. Liu, K. S. Maisinger, L. J. Murray, B. Obradovic, T. Ost, M. L. Parkinson, M. R. Pratt, I. M. J. Rasolonjatovo, M. T. Reed, R. Rigatti, C. Rodighiero, M. T. Ross, A. Sabot, S. V. Sankar, A. Scally, G. P. Schroth, M. E. Smith, V. P. Smith, A. Spiridou, P. E. Torrance, S. S. Tzonev, E. H. Vermaas, K. Walter, X. L. Wu, L. Zhang, M. D. Alam, C. Anastasi, I. C. Aniebo, D. M. D. Bailey, I. R. Bancarz, S. Banerjee, S. G. Barbour, P. A. Baybayan, V. A. Benoit, K. F. Benson, C. Bevis, P. J. Black, A. Boodhun, J. S. Brennan, J. A. Bridgham, R. C. Brown, A. A. Brown, D. H. Buermann, A. A. Bundu, J. C. Burrows, N. P. Carter, N. Castillo, M. C. E. Catenazzi, S.

Chang, R. N. Cooley, N. R. Crake, O. O. Dada, K. D. Diakoumakos, B. Dominguez-Fernandez, D. J. Earnshaw, U. C. Egbujor, D. W. Elmore, S. S. Etchin, M. R. Ewan, M. Fedurco, L. J. Fraser, K. V. F. Fajardo, W. S. Furey, D. George, K. J. Gietzen, C. P. Goddard, G. S. Golda, P. A. Granieri, D. E. Green, D. L. Gustafson, N. F. Hansen, K. Harnish, C. D. Haudenschild, N. I. Heyer, M. M. Hims, J. T. Ho, A. M. Horgan, K. Hoschler, S. Hurwitz, D. V. Ivanov, M. Q. Johnson, T. James, T. A. H. Jones, G. D. Kang, T. H. Kerelska, A. D. Kersey, I. Khrebtukova, A. P. Kindwall, Z. Kingsbury, P. I. Kokko-Gonzales, A. Kumar, M. A. Laurent, C. T. Lawley, S. E. Lee, X. Lee, A. K. Liao, J. A. Loch, M. Lok, S. J. Luo, R. M. Mammen, J. W. Martin, P. G. McCauley, P. McNitt, P. Mehta, K. W. Moon, J. W. Mullens, T. Newington, Z. M. Ning, B. L. Ng, S. M. Novo, M. J. O'Neill, M. A. Osborne, A. Osnowski, O. Ostadan, L. L. Paraschos, L. Pickering, A. C. Pike, A. C. Pike, D. C. Pinkard, D. P. Pliskin, J. Podhasky, V. J. Quijano, C. Raczy, V. H. Rae, S. R. Rawlings, A. C. Rodriguez, P. M. Roe, J. Rogers, M. C. R. Bacigalupo, N. Romanov, A. Romieu, R. K. Roth, N. J. Rourke, S. T. Ruediger, E. Rusman, R. M. Sanches-Kuiper, M. R. Schenker, J. M. Seoane, R. J. Shaw, M. K. Shiver, S. W. Short, N. L. Sizto, J. P. Sluis, M. A. Smith, J. E. S. Sohna, E. J. Spence, K. Stevens, N. Sutton, L. Szajkowski, C. L. Tregidgo, G. Turcatti, S. vandeVondele, Y. Verhovsky, S. M. Virk, S. Wakelin, G. C. Walcott, J. W. Wang, G. J. Worsley, J. Y. Yan, L. Yau, M. Zuerlein, J. Rogers, J. C. Mullikin, M. E. Hurles, N. J. McCooke, J. S. West, F. L. Oaks, P. L. Lundberg, D. Klenerman, R. Durbin and A. J. Smith (2008). "Accurate whole human genome sequencing using reversible terminator chemistry." Nature 456(7218): 53-59.

Committee on, H., C. Environmental Exposure Science in the 21st, S. Board on Environmental, Toxicology, E. Division on, S. Life and C. National Research (2012). Exposure Science in the 21st Century: A Vision and a Strategy. Washington (DC), National Academies Press (US). Copyright 2012 by the National Academy of Sciences. All rights reserved.

Costa, E., K. J. Johnson, C. A. Walker and J. M. O’Brien (2024). "Transcriptomic point of departure determination: a comparison of distribution-based and gene set-based approaches." Frontiers in Genetics Volume 15 - 2024.

Cox, J. and M. Mann (2008). "MaxQuant enables high peptide identification rates, individualized p.p.b.-range mass accuracies and proteome-wide protein quantification." Nature Biotechnology 26(12): 1367-1372.

Cox, J. and M. Mann (2011). Quantitative, High-Resolution Proteomics for Data-Driven Systems Biology. Annual Review of Biochemistry, Vol 80. R. D. Kornberg, C. R. H. Raetz, J. E. Rothman and J. W. Thorner. 80: 273-299.

Crump, D., G. Hickey, E. Boulanger, A. Masse, J. A. Head, N. Hogan, S. Maguire, J. G. Xia, M. Hecker and N. Basu (2023). "Development and Initial Testing of EcoToxChip, a Novel Toxicogenomics Tool for Environmental Management and Chemical Risk Assessment." Environmental Toxicology and Chemistry 42(8): 1763-1771.

Daigneault, P.-M. (2013). "The Blind Men and the Elephant: A Metaphor to Illuminate the Role of Researchers and Reviewers in Social Science." Methodological Innovations Online 28: 82-89.

Denslow, N. D., N. Garcia-Reyero and D. S. Barber (2007). "Fish 'n' chips: the use of microarrays for aquatic toxicology." Molecular Biosystems 3(3): 172-177.

Ebner, J. N. (2021). "Trends in the Application of "Omics" to Ecotoxicology and Stress Ecology." Genes 12(10).

Gallego-Ríos, S. E., G. A. Peñuela and E. Martínez-López (2021). "Updating the use of biochemical biomarkers in fish for the evaluation of alterations produced by pharmaceutical products." Environmental Toxicology and Pharmacology 88.

Ghasemlou, M., H. C. Nguyen, S. Talekar, F. M. Pfeffer and C. J. Barrow (2025). "Artificial Intelligence (AI) for More Sustainable Chemistry and a Greener Future." Acs Sustainable Chemistry & Engineering 13(10): 3830-3833.

Gou, X., C. Ma, H. M. Ji, L. Yan, P. P. Wang, Z. H. Wang, Y. S. Lin, N. Chatterjee, H. X. Yu and X. W. Zhang (2023). "Prediction of zebrafish embryonic developmental toxicity by integrating omics with adverse outcome pathway." Journal of Hazardous Materials 448.

Gouveia, D., C. Almunia, Y. Cogne, O. Pible, D. Degli-Esposti, A. Salvador, S. Cristobal, D. Sheehan, A. Chaumot, O. Geffard and J. Armengaud (2019). "Ecotoxicoproteomics: A decade of progress in our understanding of anthropogenic impact on the environment." Journal of Proteomics 198: 66-77.

Harrill, J. A., M. R. Viant, C. L. Yauk, M. Sachana, T. W. Gant, S. S. Auerbach, R. D. Beger, M. Bouhifd, J. O'Brien, L. Burgoon, F. Caiment, D. Carpi, T. Chen, B. N. Chorley, J. Colbourne, R. Corvi, L. Debrauwer, C. O'Donovan, T. M. D.

Ebbels, D. R. Ekman, F. Faulhammer, L. Gribaldo, G. M. Hilton, S. P. Jones, A. Kende, T. N. Lawson, S. B. Leite, P. E. G. Leonards, M. Luijten, A. Martin, L. Moussa, S. Rudaz, O. Schmitz, T. Sobanski, V. Strauss, M. Vaccari, V. Vijay, R. J. M. Weber, A. J. Williams, A. Williams, R. S. Thomas and M. Whelan (2021). "Progress towards an OECD reporting framework for transcriptomics and metabolomics in regulatory toxicology." Regulatory Toxicology and Pharmacology 125.

Himmelfarb, J., P. Stenvinkel, T. A. Ikizler and R. M. Hakim (2002). "The elephant in uremia: oxidant stress as a unifying concept of cardiovascular disease in uremia." Kidney Int 62(5): 1524-1538.

Knapen, D., M. M. Angrish, M. C. Fortin, I. Katsiadaki, M. Leonard, L. Margiotta-Casaluci, S. Munn, J. M. O'Brien, N. Pollesch, L. C. Smith, X. W. Zhang and D. L. Villeneuve (2018). "Adverse outcome pathway networks I: Development and applications." Environmental Toxicology and Chemistry 37(6): 1723-1733.

Madeira, C. and P. M. Costa (2021). Proteomics in systems toxicology. Proteomics and Systems Biology. R. Donev and T. KarabenchevaChristova. 127: 55-91.

Mardis, E. R. (2008). "Next-generation DNA sequencing methods." Annual Review of Genomics and Human Genetics 9: 387-402.

Mardis, E. R. (2017). "DNA sequencing technologies: 2006-2016." Nature Protocols 12(2): 213-218.

Marrone, B. L., S. Banerjee, A. Talapatra, C. R. Gonzalez-Esquer and G. Pilania (2023). "Toward a Predictive Understanding of Cyanobacterial Harmful Algal Blooms through AI Integration of Physical, Chemical, and Biological Data." Acs Es&T Water 4(3): 844-858.

Martyniuk, C. J. (2018). "Are we closer to the vision? A proposed framework for incorporating omics into environmental assessments." Environmental Toxicology and Pharmacology 59: 87-93.

Metzker, M. L. (2010). "APPLICATIONS OF NEXT-GENERATION SEQUENCING Sequencing technologies - the next generation." Nature Reviews Genetics 11(1): 31-46.

Min, E. K., H. Y. J. Lee, E. J. Sung, S. W. Seo, M. Y. H. Song, S. J. Wang, S. S. Kim, M. A. Bae, T. Y. Kim, S. K. Y. Lee and K. T. Kim (2023). "Integrative multi-omics reveals analogous developmental neurotoxicity mechanisms between perfluorobutanesulfonic acid and perfluorooctanesulfonic acid in zebrafish." Journal of Hazardous Materials 457.

Mittal, K., J. Ewald, D. Crump, J. Head, M. Hecker, N. Hogan, J. G. Xia and N. Basu (2024). "Comparing Transcriptomic Responses to Chemicals Across Six Species Using the EcoToxChip RNASeq Database." Environmental Toxicology and Chemistry.

Nesatyy, V. J. and M. J. F. Suter (2007). "Proteomics for the Analysis of Environmental Stress Responses in Organisms." Environmental Science & Technology 41(20): 6891-6900.

Olesti, E., V. González-Ruiz, M. F. Wilks, J. Boccard and S. Rudaz (2021). "Approaches in metabolomics for regulatory toxicology applications." Analyst 146(6): 1820-1834.

Osman, A. I., Y. B. Zhang, M. Farghali, A. K. Rashwan, A. S. Eltaweil, E. M. Abd El-Monaem, I. M. A. Mohamed, M. M. Badr, I. Ihara, D. W. Rooney and P. S. Yap (2024). "Synthesis of green nanoparticles for energy, biomedical, environmental, agricultural, and food applications: A review." Environmental Chemistry Letters 22(2): 841-887.

Pollard, S., J. C. Anderson, F. Bah, M. Mateus, M. Sidhu and D. B. D. Simmons (2022). "Non-Lethal Blood Sampling of Fish in the lab and Field With Methods for Dried Blood Plasma Spot Omic Analyses." Frontiers in Genetics 13.

Portugal, J., S. Mansilla and B. Piña (2022). "Perspectives on the Use of Toxicogenomics to Assess Environmental Risk." Frontiers in Bioscience-Landmark 27(10).

Revel, M., K. Groh, J. Bertoli, M. O. Degeratu, M. Fischer, S. Fischer, J. Hoekman, B. Jozef, R. Li, S. L. Mosimann, C. vom Berg, A. Zupanic, B. Truffer and K. Schirmer (2025). "Development of the fish invitrome for animal-free environmental risk assessment of chemicals." Environmental Toxicology and Chemistry.

Shi, C., L. Cheng, Y. Yu, S. Chen, Y. Dai, J. Yang, H. Zhang, J. Chen and N. Geng (2024). "Multi-omics integration analysis: Tools and applications in environmental toxicology." Environmental Pollution 360: 124675.

Shi, C. C., L. Cheng, Y. Yu, S. S. Chen, Y. B. Dai, J. J. Yang, H. J. Zhang, J. P. Chen and N. B. Geng (2024). "Multi-omics integration analysis: Tools and applications in environmental toxicology ." Environmental Pollution 360.

Simmons, D. B. D. and V. Palace (2022). "Non-lethal approaches in environmental science." Frontiers in Genetics 13.

Sun, J. C., R. C. Fang, H. Wang, D. X. Xu, J. Yang, X. C. Huang, D. Cozzolino, M. L. Fang and Y. C. Huang (2022). "A review of environmental metabolism disrupting chemicals and effect biomarkers associating disease risks: Where exposomics meets metabolomics." Environment International 158.

Valavanidis, A., T. Vlahogianni, M. Dassenakis and M. Scoullos (2006). "Molecular biomarkers of oxidative stress in aquatic organisms in relation to toxic environmental pollutants." Ecotoxicology and Environmental Safety 64(2): 178-189.

Viant, M. R., T. M. D. Ebbels, R. D. Beger, D. R. Ekman, D. J. T. Epps, H. Kamp, P. E. G. Leonards, G. D. Loizou, J. I. MacRae, B. van Ravenzwaay, P. Rocca-Serra, R. M. Salek, T. Walk and R. J. M. Weber (2019). "Use cases, best practice and reporting standards for metabolomics in regulatory toxicology." Nature Communications 10(1): 3041.

Villeneuve, D. L., D. Crump, N. Garcia-Reyero, M. Hecker, T. H. Hutchinson, C. A. LaLone, B. Landesmann, T. Lettieri, S. Munn, M. Nepelska, M. A. Ottinger, L. Vergauwen and M. Whelan (2014). "Adverse Outcome Pathway (AOP) Development I: Strategies and Principles." Toxicological Sciences 142(2): 312-320.

Wang, P. P., P. Xia, Z. H. Wang and X. W. Zhang (2020). "Evidence-based assessment on environmental mixture using a concentration-dependent transcriptomics approach." Environmental Pollution 265(PT A).

Yates, J. R., C. I. Ruse and A. Nakorchevsky (2009). "Proteomics by Mass Spectrometry: Approaches, Advances, and Applications." Annual Review of Biomedical Engineering 11: 49-79.

CHAPTER 7

Reflecting on the last fifty years of society and environmental contaminants: Evolution of science, technology and public policy

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Introduction

Although the rapid development of synthetic chemicals promised a better future, their adverse effects on humans and the environment soon became apparent. These concerns led to the emergence of the environmental movement of the 1970s and the formation of environmental agencies and departments in government. Early pesticides and industrial chemicals were persistent in the environment, transported globally and bioaccumulated in food chains. Although remarkable progress has been made on assessment, control and "virtual elimination" of legacy pollutants, other chemicals continue to emerge and/or replace them. Advances in analytical chemistry have continued to reveal the presence of many chemicals and their transformation products in the environment that may have previously been seen as environmentally benign (e.g., pharmaceuticals, tires, plastics). As we learn more about their properties, environmental pathways, and toxicology we are better able to predict adverse outcomes and take remedial action. However, the regulatory response can be slow, and humans continue to develop novel chemicals at a startling pace. The lessons of the past may help us to predict and be prepared for the issues of the

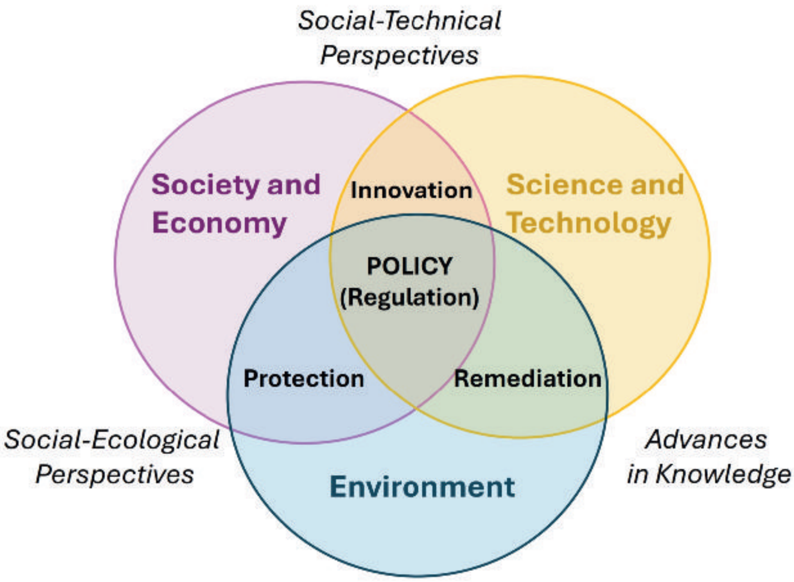

Figure 1: Diagram showing the intersecting relationship between society, economy, science, technology and the environment and how changing perspectives and advances in knowledge can drive policy innovation for environmental protection and remediation.

future. It is not possible to think about the history of environmental contamination without placing it in the context of societal and technological change. While the world population hit one billion in 1804 it is now more than 8.2 billion (https://www.worldometers.info/world-population/). Since the creation of the Canadian Ecotoxicity Workshop in 1974 (CEW, formerly known as the Aquatic Toxicity Workshop, ATW), the world population has more than doubled. This rapid population growth has paralleled a dramatic increase in the extraction and use of natural resources, as demands escalated for food, clothing, housing, energy, and other products. The development of synthetic chemicals at the turn of the century promised to solve many emerging societal problems and transform how we lived. The downside of new chemicals soon became evident as they spread around the globe and negative impacts on both humans and the environment emerged (Lohmann et al. 2007). Recognition of these threats and growing environmental awareness led to the establishment of many regulatory agencies and actions in Canada and around the world. Although the risk management of synthetic chemicals over the last few decades has in many ways been a success story, many challenges remain.

The demands of growing and changing populations have driven innovation that has led to prosperity but also environmental degradation. Social-economic and social-technological perspectives and priorities of society have and will continue to evolve. However, new knowledge, adaptive management and informed policy can ensure environmental protection, effective remediation, and a sustainable future (Figure 1).

During the past 50 years of major advancements in the field of toxicology, the Canadian Ecotoxicity Workshop has played a key role in building and communicating the foundations of the science used to predict, assess, regulate, and remediate environmental contaminants. This chapter explores the introduction of industrial and synthetic chemicals to society and its impact on environmental contamination in Canada and worldwide. We also explore the historical context of technological advances and changing societal values that contributed to adverse impacts but also increased our ability to detect and address issues of environmental contamination.

Figure 2: Image of the Toronto waterfront around 1912 (Skyline, Fonds 1244 >item 1122 A, Toronto Archives, public domain photo, https://7078.sydneyplus.com/archive/final/Portal/Default.aspx?lang=en-CA).

The Industrial Revolution, Pollution and Early Environmental Regulations

The industrial revolution brought huge economic progress and potential. The first industrial revolution, spanning from the 1700s to mid-1800s, came with dramatic advancements in the ability to mass produce products using steam power and mechanization to be able to meet the needs of the growing populations. As the population grew, industries expanded and people moved into cities, there was increased pressure for resources and problems arose related to waste management and pollution.

In the early 1800s the Leblanc alkali process was introduced to create the large amounts of sodium carbonate (soda) needed for the growing soap and glass industry. By the mid-1800s acid rain from the alkali process was such a human health and property damage problem that the United Kingdom introduced the Alkali Act (1863). The act required the installation of scrubbers to remove at least 95% of acid gas and led to dramatic reductions in hydrogen chloride emissions (Fowler et al. 2020). The Alkali Act introduced the concept of regulating emissions and set a precedent for future environmental regulations.

At this same time, industrial inorganic chemicals like lead and mercury were also causing significant environmental and human health impacts. While initially nuisance laws allowed individuals to seek legal action against companies causing harm, the Alkali Act was expanded to include additional industrial chemicals.

Another example of early government regulations in response to societal (human health) impacts of economic and technological growth was the Public Health Act for London in 1875. Decades of burning coal in homes and industries resulted in air pollution, respiratory illness, and death. At its peak 1-in-350 people died from bronchitis and frequent, severe fogs impacted transportation and economic activities and increased crime in London (Fouquet 2011) that led to societal prioritization of investing in technologies and policies to protect human health. The Public Health Act (UK) required a shift towards cleaner and more efficient coal burning and industrial emission practices and led to rapid decline in suspended particulate matter in major cities like London (Fowler et al. 2020). Despite these regulatory actions, the “Great Smog of London” in 1952 caused as many as 12,000 deaths and led to the creation of the

Figure 3: Pennsylvania Salt Manufacturing Company advertisement for DDT that appeared in Time Magazine, June 30, 1947 (Science History Institute, public domain, https://digital.sciencehistory.org/works/1831ck18w).

Clean Air Act (1956).

In addition to air quality issues, poor public sanitation and direct dumping of industrial waste led to water quality issues. In 1858, the Thames River was essentially an open sewer, and a heat wave caused the "Great Stink" that led to political action to divert sewers downstream (Ashton 2017). In Canada creeks and rivers in highly populated cities in the 1800s were open sewers (Figure 2). Scientific studies led to clear evidence that cleaning up water and air would reduce disease burdens. Although pollution was recognized as a public health issue it was not until much later that environmental health was linked to human wellbeing and sustainability. It was not until the 1900s that municipal treatment plants became common (e.g., the first large treatment plant in Canada was built in Hamilton in 1896). The turn of the century also saw major innovations in industrial process and chemistry, and the introduction of a diversity of environmental contaminants.

The Promise and Perils of New Chemicals

While early innovations in the mid-1800s led to synthetic dyes, explosives, artificial fibres, anesthetics and pharmaceuticals, beginning in the 1930s the development of new chemicals greatly expanded. After World War II there was a major rise in the petrochemicals industry (e.g., synthetic rubber, chemicals, plastics). The 1940s saw the rise of many synthetic chemicals, including pesticides, that promised a better future by making life safer, easier, and less expensive. New synthetic chemicals were thought of as a miracle of technology that reduced disease and pests, improved agricultural productivity, and provided less expensive and new products. However, negative impacts would soon start to emerge and become a public concern. One such miracle chemical was the synthetic pesticide DDT (dichloro-diphenyl-trichloroethane). During WWII, American soldiers dusted more than a million Italians with DDT, killing the body lice that spread typhus and saving the city from a devastating epidemic. The use of DDT became widespread as a new "wonder-chemical" for prevention of human disease and the protection of agricultural crops and livestock (Figure 3).

DDT, and other pesticides, were enthusiastically embraced by society but scientists soon became concerned about its impacts on non-target organisms. In 1962 the publication of "Silent Spring" (Carson 1962) raised public concern for the impacts of pesticides (biocides) on humans and the environment. Carson

Figure 4: Earthrise from Apollo 8, 1968 (NASA, public domain photo, https://science.nasa.gov/resource/image-earthrise/).

Figure 5: The first Earth Day. April 1970. Calgary Herald, Antipollution parade, Calgary Alberta. Image No. NA-2864-5922, Courtesy of Digital Collections, University of Calgary. https://digitalcollections.ucalgary.ca/asset-management/2R3BF1OCNXPS?&WS=SearchResults&Flat=FP.

wrote, “How could intelligent beings seek to control a few unwanted species by a method that contaminated the entire environment and brought the threat of disease and death even to their own kind?”. Although Carson was initially heavily criticized, her work led to US congressional hearings and a broad recognition of the need for conservation and additional regulation (Werner and Bettina 2012). DDT was soon phased out of agriculture in the 1970s, although it remained in use for some limited applications (e.g., indoor malaria control) and lingers as a persistent legacy in many environments.

Despite the shift of social-ecological perspectives toward environmental protection in the 1960s many environmental disasters continued to occur. Chemical production and inappropriate disposal led to many issues such as Times Beach, Missouri, where the production of 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) created the bi-product polychlorinated dibenzo-p-dioxin (Hites et al. 2011). The inappropriate disposal of toxic waste in the Love Canal in the 1940s later led to major health issues and continued to raise public awareness (Gill and Mix 2020). Mining waste, acid mine drainage, petroleum and oil sands extraction have created ecological concerns across Canada (Schindler 2011). Widespread industrial pollution of sewers and waterways became a major concern with many harbours and rivers having water and sediments that were highly toxic and impairing aquatic resources. The historical pollution was so extreme at some sites that oil slicks covered the surface and choked out aquatic life. The Buffalo River caught on fire in 1968 and although the Cuyahoga River caught fire multiple times, the fire in 1969 finally raised public awareness and action (Boissoneault 2019). Although many contaminated sites represent a toxic legacy (e.g., industrial, mines, disposal), non-point sources of pollution (e.g., urban runoff, agriculture, forestry) also represent a current and historical concern. People were recognizing that clean air and water were critical for a sustained economy and quality of life. The first “earthrise” photograph from Apollo 8, Dec. 24, in 1968, provided a new human perspective of the fragility of the globe (Figure 4). This awakening sparked the environmental movement and the first Earth Day on April 22, 1970 (Dunlap and Mertig 1991; Figure 5).

Regulatory Response

Environmental policies act to encourage innovation (e.g., Best Available Technology, Economically Achievable (BATEA), set guidelines, objectives and standards for environmental protection and can direct remediation requirements for contaminated sites (Figure 1). Although the US Water Pollution Control Act (1948) and Clean Air Act (1963) were already in place, the 1970s saw many significant environmental milestones in the USA, such as the creation of the Environmental Protection Agency (1970) and the Clean Water Act (1972). Similarly, prompted by new social awareness and environmental concerns, the Canadian Department of the Environment was created in 1971, and the Great Lakes Water Quality Agreement was signed between Canada and the United States in 1972. Additional legislation and regulations in Canada focused on environmental protection were also established including a focus on toxic chemicals in air, water and soil (e.g., Fisheries Act Amendments 1970, Clean Air Act 1971, Pulp and Paper Effluent Regulations 1971, Canada Water Act 1971, Arctic Waters Pollution Prevention Act 1972, Environmental Assessment and Review Process, 1973). Although the Fisheries Act dates to 1868, the Canadian Environmental Protection Act (CEPA) was established in 1988 and the Pest Control Products Act in 2002.

In Canada responsibility for the protection of the environment is divided between the Federal and Provincial governments with each province establishing its own legislation and standards. The provinces have jurisdiction over most matters related to natural resources as well as measures for their protection. In addition, municipalities play a role in environmental protection and can pass a variety of by-laws related to environmental protection (e.g. sewage, land use, etc.). The regulatory environment across Canada is therefore complex.

Recognition that pollution was not just a local issue, but a global one, led to international cooperation to address Persistent Organic Pollutants (POPs) such as DDT, chlordane, toxaphene, mirex, dieldrin, heptachlor, PCBs, hexachlorobenzene, dioxins, and furans. These chemicals could be transported long distances, concentrated in remote, cold northern environments and bioaccumulate in food webs (Muir et al 1992; Borgå et al. 2022). This led to the establishment of international transboundary agreements like the Convention on Long-Range Transboundary Air Pollution in 1979 and the Stockholm

Convention in 2004. There are continuing international efforts to coordinate and ensure sound management of chemicals globally (e.g., Canada's Strategic Approach to International Chemicals Management).

Emerging Tools for Environmental Analysis

Rapid developments in analytical chemistry have led to innovations in extraction, separation (i.e., chromatography) and detection (e.g., mass spectrometry) and their integration. There was a move away from solvent extraction to more efficient and selective solid-phase (SPE) techniques (Badawy et al. 2022). Developments in solid-phase microextraction (SPME) have also seen major advances and application (Zheng et al. 2023). The transition from packed columns to capillary allowed for the better separation of very closely related chemicals (Mametov et al. 2021). The development of new detectors, including flame ionization and electron capture allowed for very sensitive detection especially for halogenated contaminants (Santos and Galceran 2002). The integration of chromatography with advances in mass spectrometry enabled the sensitive and selective detection of a wide variety of closely related chemicals (Santos and Galceran 2003). Gas chromatography was limited to mostly non-polar volatile compounds, but the development of electrospray ionization enabled the linking of mass spectrometers to liquid chromatography (Holčapek et al. 2012). This breakthrough won J. Fenn, K. Tanaka and K. Wüthrich the 2002 Nobel Prize and led to the detection of a new world of chemicals/contaminants. In parallel developments in mass spectrometry, including high-resolution instruments, has allowed for accurate mass detection and separation (Petrovic et al. 2010; Hernandez et al. 2012). These advances combined with the ability to process large data sets, allowed for the emergence of non-target analysis and the exploration of complex matrices (González-Gaya et al. 2021). Although mass spectrometry has been the dominant tool in organic contaminant analysis for the last few decades, many innovations are occurring for metals (Jin et al. 2020), nanoparticles (Jiang et al. 2022), plastics (Huang et al. 2023), etc, that will create additional tools in the future. However, many challenges for identification, detection and quantification of the diversity of emerging contaminants of concern in the environment remain (Muir et al. 2006; Richardson and Manasfi 2024).

Unexpected Consequences

In the early 1990s, it was recognized that traditional approaches to assess effects were missing important impacts of many chemicals in humans and wildlife. "Our Stolen Future" (Colborn et al. 1996) grabbed public attention by highlighting how mostly unregulated environmental contaminants could cause endocrine disruption. The 1991 Wingspread Conference highlighted how chemicals at very low concentrations could alter reproduction and development in humans and wildlife (Hotchkiss et al. 2008). These chemicals are very diverse, but many tend to be more polar than POPs and many have different sources (e.g., estrogens, personal care products, pharmaceuticals) making many of them pseudo-persistent.

Contaminants, including their degradation products, usually exist and interact as complex mixtures. These chemicals can have similar or very different modes of action making prediction of the effect of mixtures very difficult (Escher et al. 2020). Effect-directed analysis (EDA) or toxicity identification evaluation (TIE) has been used to identify bioactive chemicals in complex matrices such as pesticides formulation, wastewaters and environmental samples (Brack et al. 2016). Modelling has become an option for screening of chemicals and trying to identify possible causal agents in environmental mixtures (Muir et al. 2019). Many substances are complex mixtures of closely related structures, isomers and even enantiomers. A good example is per- and polyfluoroalkyl substances (PFAS), that is a group of more than 15,000 chemicals. PFAS have been used in diverse products since the 1950s but only recently were identified as a risk and regulated. The identification, separation and analysis of chemicals in complex mixtures is difficult and associating chemicals to effects of these mixtures remains a major challenge.

Continued Challenges

Despite the abundance of water resources across Canada, regional differences in the distribution of water, increased demand and pollution have led to a variety of issues, and climate change may create further stress in the future (Schindler 2001). New chemicals continue to be produced, identified and detected, presenting ongoing challenges for science and regulators. Legacy issues like metal contamination are emerging again as the transition to low-carbon economies increase mining and use of critical minerals and rare earth elements.

Chemicals usually exist in the environment as complex mixtures, such as in municipal/industrial wastewater effluents, agricultural/urban runoff, and legacy contaminants. Assessing the risk of mixtures and determining how to remediate them is a significant uncertainty and continuing scientific challenge. Contaminants almost never exist in isolation and many other stressors can alter their fate and effects. We do not yet fully understand how contaminants interact with other stressors (e.g., invasive species, habitat change, eutrophication) or know how to prioritize remedial actions. Climate change is a contributing factor by altering exposure patterns to ecosystems, modifying chemical fate and/or changing how organisms respond.

Are we underestimating risks because we are not using approaches or regulations that incorporate mixture effects? Cumulative factors are at play, and we are still managing chemicals individually despite knowing that they almost always occur as complex mixtures and in the presence of other stressors.

Optimism for the Future

Despite the challenges facing the Canadian environment, there have been huge improvements:

- Better regulatory tools are in place, reducing environmental exposure to many chemicals.
- Improved risk assessments are based on a better understanding of sources, fate, effects, and risk.
- Better monitoring programs are in place.
- Advanced technology is available to mitigate and remediate contaminants.
- Public engagement and support for environmental protection have increased.

Despite the massive environmental challenges faced in the past there have been significant improvements over the last 50 years which is cause for optimism. The Fisheries Act was modernized in 2019 and CEPA in 1999/2023 to improve fisheries and environmental protection and included a greater commitment to indigenous rights. CEPA (2023) now includes a recognition of the right to a healthy environment and mandates that the federal government consider the cumulative effects of toxic substances, especially on vulnerable populations. Continued advances in analytical tools, improvements in wastewater treatment, pollution reduction technologies, growth in green chemistry and chemical alternatives, advancements in computer modeling (e.g., Quantitative Structure-Activity Relationships, read-across methods, cross-species extrapolation), and the ability to exploit big data and machine learning, all contribute to a brighter future. However, it is also important to remain vigilant and learn from past mistakes. Effective management of chemicals will support the economy, protect human and environmental health and ensure a sustainable future. When chemicals are used wisely and managed appropriately, they can contribute greatly to a brighter and sustainable future.

Over the past 50 years, the Canadian Ecotoxicity Workshop has played a key role in building and communicating the foundations of science used to predict, assess, regulate, and remediate environmental contamination. Going forward, the need to share information and collaborate on current and emerging topics related to environmental contamination remains as important as ever. Economic, technological and ecological perspective will continue to change and alter how Canadian society values and prioritizes environmental protection and sustainability. CEW will continue to be a critical component of addressing emerging environmental issues across Canada and beyond into the future.

References

Ashton, R. 2017. One Hot Summer: Dickens, Darwin, Disraeli, and the great stink of 1858. Yale University Press.352 p. ISBN 978-0-300-22726-0

Badawy M., M. El-Nouby P.K. Kimani, L.W. Lim, E.I. Rabea. 2022. A review of the modern principles and applications of solid-phase extraction techniques in chromatographic analysis. Analytical Sciences 38 (12): 1457-1487. https://doi.org/10.1007/s44211-022-00190-8

Boissoneau, L. 2019. The Cuyahoga River caught fire at least a dozen times, but no one cared until 1969. Smithsonian Magazine. Retrieved from: https://www.smithsonianmag.com/history/cuyahoga-river-caught-fire-least-dozen-times-noCarson, R. (2015). Silent spring. In Thinking about the environment (pp. 150-155). Routledge.-one-cared-until-1969-180972444/ [Online Resource]

Borga, K., M.A. McKinney, H. Routti, K.J. Fernie, J. Giebichenstein, I. Hallanger, D.C.G Muir. 2022. The influence of global climate change on accumulation and toxicity of persistent organic pollutants and chemicals of emerging concern in Arctic food webs. Environmental Science: Processes & Impacts 24(10): 1544-1576. http://doi/10/1039/D1EM00469G

Brack, W., et al. 2016. Effect-directed analysis supporting monitoring of aquatic environments—an in-depth overview. Science of the Total Environment 544: 1073-1118. https://doi.org/10.1016/j.scitotenv.2015.11.102

Carson, R. 1962. Silent spring. New York, Mass., Houghton Mifflin. ISBN 0-618-25305-x

Colborn T., D. Dumanoski, J. Myers. 1996. Our stolen future: Are we threatening our fertility, intelligence, and survival? A scientific detective story. New York, NY., Dutton. ISBN 10: 0525939822

Dunlap, R.E. and A.G. Mertig. 1991. The evolution of the US environmental movement from 1970 to 1990: An overview." Society & Natural Resources 4(3): 209-218. https://doi.org/10.1080/08941929109380755

Escher, B.I., H.M. Stapleton, E.L. Schymanski. 2020. Tracking complex mixtures of chemicals in our changing environment. Science 367(6476): 388-392. http://doi.org/10.1126/science.aay6636

Fouquet, R. 2011. Long run trends in energy-related external costs. Ecological Economics 70(12): 2380-2389. https://doi.org/10.1016/j.ecolecon.2011.07.020

Fowler, D., et al. 2020. A chronology of global air quality. Philosophical Transactions of the Royal Society A 378(2183): 20190314. https://www.jstor.org/stable/27101033

Gill, D.A. and T. L. Mix. 2020. Love canal: A classic case study of a contaminated community. In An Introduction to Interdisciplinary Toxicology, pp. 341-352. Academic Press, 2020. https://doi.org/10.1016/B978-0-12-813602-7.00025-9

González-Gaya, B., N. Lopez-Herguedas, D. Bilbao, L. Mijangos, A. M. Iker, N. Etxebarria, M. Irazola, A. Prieto, M. Olivares, O. Zuloaga. 2021. Suspect and non-target screening: the last frontier in environmental analysis. Analytical Methods 13(16): 1876-1904. https://doi.org/10.1039/D1AY00111F

Hernandez, F., J.V. Sancho, M. Ibáñez, E. Abad, T. Portolés, L. Mattioli. 2012. Current use of high-resolution mass spectrometry in the environmental sciences. Analytical and Bioanalytical Chemistry 403(5): 1251-1264. https://doi.org/10.1007/s00216-012-5844-7

Hites, R. A. 2011. Dioxins: an overview and history. Environmental Science & Technology 45(1): 16-20. https://doi.org/10.1021/es1013664

Holčapek, M., R. Jirásko, M. Lísa. 2012. Recent developments in liquid chromatography–mass spectrometry and related techniques. Journal of Chromatography A 1259: 3-15. https://doi.org/10.1016/j.chroma.2012.08.072

Hotchkiss, A.K., C.V. Rider, C.R. Blystone, V.S. Wilson, P.C. Hartig, G.T. Ankley, P.M. Foster, C.L. Gray, E. Gray. 2008. Fifteen years after "Wingspread"—environmental endocrine disrupters and human and wildlife health: where we are today and where we need to go. Toxicological Sciences 105(2): 235-259. https://doi.org/10.1093/toxsci/kfn030

Huang, Z., B. Hu, H. Wang, H. 2023. Analytical methods for microplastics in the environment: a review. Environmental Chemistry Letters, 21(1): 383-401. https://doi.org/10.3109/07388551.2015.1128876

Jiang, C., S. Liu, T. Zhang, Q. Liu, P.J.J. Alvarez, W. Chen. 2022. Current methods and prospects for analysis and characterization of nanomaterials in the environment. Environmental Science & Technology 56(12): 7426-7447. https://doi.org/10.1021/acs.est.1c08011

Jin, M., H. Yuan, B. Liu, J. Peng, L, Xu, D. Yang. 2020. Review of the distribution and detection methods of heavy metals in the environment. Analytical Methods, 12(48): 5747-5766. https://doi.org/10.1039/D0AY01577F

Lohmann, R., K. Breivik, J. Dachs, D. Muir. 2007. Global fate of POPs: current and future research directions. Environmental Pollution 150(1): 150-165. https://doi.org/10.1016/j.envpol.2007.06.051

Mametov, R., I-A. Ratiu, F. Monedeiro, T. Ligor, B. Buszewski. 2021. Evolution and evaluation of GC columns. Critical Reviews in Analytical Chemistry 51(2): 150-173. https://doi.org/10.1080/10408347.2019.1699013

Muir, D., X. Zhang, C.A. de Wit, K. Vorkamp, S. Wilson. 2019. Identifying further chemicals of emerging arctic concern based on 'in silico 'screening of chemical inventories. Emerging Contaminants 5: 201-210. https://doi.org/10.1016/j.emcon.2019.05.005

Muir, D.C.G. and P.H. Howard. 2006. Are there other persistent organic pollutants? A challenge for environmental chemists. Environmental Science & Technology 40(23): 7157-7166. https://doi.org/10.1021/es061677a

Muir, D.C.G., R. Wagemann, B. T. Hargrave, D. J. Thomas, D. B. Peakall, R. J. Norstrom. 1992. Arctic marine ecosystem contamination. Science of the Total Environment 122(1-2): 75-134.https://doi.org/10.1016/0048-

9697(92)90246-O

Petrovic, M., M. Farré, M. Lopez De Alda, S. Perez, C. Postigo, M. Köck, J. Radjenovic, M. Gros, D. Barcelo. 2010. Recent trends in the liquid chromatography–mass spectrometry analysis of organic contaminants in environmental samples. Journal of Chromatography A 1217 (25): 4004-4017. https://doi.org/10.1016/j.chroma.2010.02.059

Richardson, S.D. and T. Manasfi. 2024. Water analysis: emerging contaminants and current issues. Analytical Chemistry 96(20): 8184-8219. https://doi.org/10.1021/acs.analchem.4c01423

Russell, C.A., S.A.H. Wilmot, V. Campbell, N.G. Coley. 2000. Chemistry, society and environment: A new history of the British chemical industry. Cambridge: Royal Society of Chemistry. 388 pages ISBN 13: 9780854045990

Santos, F. J. and M. T. Galceran. 2003. Modern developments in gas chromatography–mass spectrometry-based environmental analysis. Journal of Chromatography A 1000(1-2): 125-151. https://doi.org/10.1016/S0021-9673(03)00305-4

Santos, F. J., and M. T. Galceran. 2002. The application of gas chromatography to environmental analysis. Trends in Analytical Chemistry 21(9-10): 672-685. https://doi.org/10.1016/S0165-9936(02)00813-0

Schindler, D.W. 2001. The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. Canadian Journal of Fisheries and Aquatic Sciences 58(1): 18-29.

Werner, I. and B. Hitzfeld. 2012. 50 years of ecotoxicology since silent spring–A review. GAIA-Ecological Perspectives for Science and Society 21(3): 217-224. https://doi.org/10.14512/gaia.21.3.13

Zheng, J., Y. Kuang, S. Zhou, X. Gong, G. Ouyang. 2023. Latest improvements and expanding applications of solid-phase microextraction. Analytical Chemistry 95(1): 218-237. https://doi.org/10.1021/acs.analchem.2c03246

CHAPTER 8

Evolution of environmental monitoring studies presented at the Canadian Ecotoxicity Workshop: past trends and future tools

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Introduction

Shortly after John Sprague published his methods for bioassay testing (Sprague, 1969, 1973), scientists interested in developing toxicity testing methods began to meet at the Aquatic Toxicity Workshop. In the early years, the conference focused primarily on laboratory test methods for acute and sublethal bioassays, with far fewer studies focused on model ecosystems and field studies of effluent toxicity. We reviewed the studies in the abstract books from 1974 to 2019 to analyze changes in focus as ATW/CEW matured.

A few qualifications: when multiple endpoints were measured, the studies were characterized by the highest level examined (i.e., a study on sediment chemistry and benthic community structure was characterized as "benthic community") and studies on microplastics and eDNA were characterized as "water quality." Studies that took field-collected samples to the laboratory for toxicity testing were not classified as "environmental monitoring".

Over the time period from 1974 to 2019, 38.1% of 5773 abstracts were classified as "environmental monitoring" and 29.9% (657/2198) of these were focused solely on chemical measurements. Of these chemical measurement studies, 54.0% were focused on water chemistry, 37.7% were focused on sediment chemistry and the remainder were split between soil (3.6%), groundwater and air (1.5% each), and snow (0.6%).

Over the first three conferences (1974 Winnipeg, 1975 Toronto, 1976 Halifax), <5% of studies presented results from field studies. Up until 1979, only 25/145 (17%) of presentations focused on field studies, and the dominant topics in field studies throughout the 1970s (>50% of field studies) were documentation of chemical levels in water, field-conducted bioassays, and a few studies on benthic macroinvertebrate communities. The remaining field studies (40%) were conducted on fish, and included biochemistry, reproduction, behaviour and growth endpoints. Metals were the focus of most field studies.

During the 1980s, the number of talks doubled (from an average of 24.2 to 50.8) and environmental monitoring studies increased from 17% to 28%. Studies focused on sediment chemistry (6.5%) were almost as common as water chemistry (7.6%), and results of work on industrial chemicals and persistent organic chemicals appeared. Almost 60% of field studies were conducted on fish, whereas 16% were conducted on invertebrates. Documentation of tissue chemistry levels accounted for almost 40% of environmental monitoring studies (including studies focused solely on water and sediment chemistry takes the total to >50%). The next most common studies included physiological research on fish and bivalves, and benthic communities also received more attention. After 1984, fish studies focused on fish cancer, tumours, and neoplasms. The first few studies on birds and mammals appeared (<4% of studies), with an equal number of studies documenting chemical levels and physiological markers. Throughout the 1970s and 1980s the primary contaminants of concern were metals, industrial chemicals, and persistent, biomagnifying chemicals, such as PCBs.

During the 1990s, the average number of talks presented at each meeting almost tripled (average of 149) and the frequency of environmental monitoring studies increased to an average of 35.9%. Part of this change can be attributed to implementation of Environmental Effects Monitoring (EEM) requirements which were under development in 1990; requirements for pulp and paper mills promulgated in 1992 as part of new Pulp and Paper Effluent regulations that fell under the Fisheries Act. The emergence of EEM increased the focus on whole organism endpoints in fish and community metrics in benthic invertebrates, and monitoring methods influenced the design of field studies in other sectors and countries. The Aquatic Toxicity Workshop became a major focal site for EEM discussions, with the National Science Team coordinating their annual meetings with the timing of the conferences. The EEM National Science Team was a group of regulators, government scientists, and academics that functioned to provide some national consistency in EEM study designs.

Studies focused solely on water or sediment chemistry had fallen from 25% in the 1970s, to around 14% on the 1980s but increased again to >25% in the 1990s as the focus on organic contaminants increased; sediment chemistry studies were 50% higher than water quality-focused studies. The first studies focused on groundwater chemistry, soil chemistry and snow chemistry emerged.

In addition to shifting the emphasis more towards effluent and field assessments, emerging understanding of the endocrine disrupting effects of pulp and paper mill effluent in the 1990 conference increased focus on endocrine disrupting chemicals. For fish and invertebrate studies, 28% of studies focused on documenting chemical levels in tissue, with the next most common studies focused on physiological indicators (26%), EEM endpoints (22%), benthic community structure (6%) and tumours in fish (6%). In the 1990s, studies on birds and mammals increased to represent almost 13% of total environmental monitoring studies, and more than 70% were focused on documenting chemical levels in tissues. The first few amphibian studies also appeared in the 1990s.

During the 2000s, the number of talks continued to increase (average 203), as did the proportion of field studies (43.9%). Studies focused on water and sediment chemistry were roughly equal (15.9% versus 13.8%), with 1.7% focused on other media. The proportions of field studies focused on fish (35.1%) and benthic invertebrates (24.1%) were similar to the 1990s, and the dominant focus was on documenting chemical levels (combined 27%), followed closely by EEM-focused studies (26%). Endocrine disruption accounted for 22% of fish studies, and benthic community investigations continued to comprise a significant proportion of invertebrate studies (28% of benthic studies).

Studies in amphibians increased slightly (total of 8 studies) in the 2000s, and although birds and mammal studies were roughly equal, 65% were focused on documenting chemical levels. The emergence of pharmaceuticals and personal care products, nanomaterials, and flame retardants accounted for much of the increased focus.

During the 2010s, the average number of abstracts dropped (average 166) as did the proportion of abstracts focused on environmental monitoring (37.4%). There was a dramatic increase in studies focused on water chemistry (25.6%), a drop in sediment chemistry (7.6%) and an increase in soil chemistry (2.6%); part of the explanation is the emergence of microplastics and eDNA studies which were classified as water quality studies. EEM studies declined substantially, with fish studies dominated by chemical analyses (>43%), followed by physiological studies (29% of fish studies) and benthic invertebrate community studies. Studies on birds (6.0%), mammals, and amphibians/reptiles (3.4%) doubled, with the dominant focus on chemical levels (>60% total, 85% in mammalian studies).

EEM studies varied due to the cyclical nature of EEM programs, with an increased focus in 2015 that coincided with the 25th anniversary of EEM program implementation. Environmental monitoring studies peaked in the 2000s and declined in the 2010s as there was an increased frequency of talks on management issues and cumulative effects. Emerging topics in the 2010s included microbiome sampling, microplastics, omics technologies (although studies were more frequently lab-based studies) and eDNA approaches used to assess fish and benthic invertebrate community structure.

Community-based Monitoring

The emergence of Indigenous-focused field studies was slow. The first abstract mentioning community-based monitoring (CBM) was submitted in 2013, aboriginal engagement emerged in 2014 and traditional environmental knowledge (TEK) in 2015. CBM is the practice of community members leading or assisting in the collection of environmental data. CBM includes citizen science projects, where members of the public volunteer their time to collect data. Indigenous-led monitoring programs included community members collecting data either as volunteers or paid monitors. In the mid-2010s, CBM was beginning to be recognized for its capacity to collect robust environmental data that could support research and decision-making rather than just as stewardship and engagement initiatives (Follett & Strezov, 2015; Kanu et al., 2016).

CBM was first mentioned at CEW 2013 in a talk about the Slave Watershed Environmental Effects Program (SWEEP), which aimed to address community concerns about water quality and potential human and wildlife health effects (Slave River and Delta Partnership, 2017). The first CBM-focused session occurred in 2016. Overall, CEW talks that had a CBM focus tended to be about projects with Indigenous communities in northern regions in Canada, and more recently in Atlantic Canada. In these talks, CBM was generally discussed as having the potential to enhance environmental monitoring programs, incorporate local knowledge, and address community concerns about environmental impacts. In recent years, the development of cutting-edge technologies has seen more inclusive monitoring approaches that increasingly involve community members in data collection. For example, CEW 2022 talk “Gone Fishing”: Using eDNA and citizen science to assess the presence of stocked fishes in Fort Whyte Alive’s lakes, discussed a citizen science project that involved high school students to collect samples for eDNA analysis (Khan et al., 2022).

Not all CBM projects are designed for the same purpose, resulting in a wide spectrum of program design (Kanu et al., 2016). Some CBM projects are designed and led by scientists from outside of the community, with objectives that prioritize research questions rather than local community concerns (Danielsen et al., 2008; Kipp et al., 2019). Alternatively, community-led CBM projects are designed by community members who lead the collection of data and fulfill community objectives that support local environmental decision-making (Danielsen et al., 2008). Community-led CBM is gaining popularity as there are increasing calls for more meaningful participation of communities in environmental decision-making (Reed et al., 2020).

In the 2020s, there has been an increased focus on Indigenous participation in ecotoxicology, Indigenous environmental governance, addressing colonialism in environmental monitoring, and various approaches to blending, weaving, and braiding Western and Indigenous approaches. Indigenous scientists and community members are playing an increasing role in presenting CBM projects at meetings, and the focus is increasingly shifting towards Indigenous-led initiatives and co-production rather than externally-driven projects.

Open data initiatives

The application of monitoring data is evolving from single to multi-purpose as Open Data initiatives prompt researchers to make their data more findable, accessible, interoperable, and reusable (Roche et al., 2020). Large amounts of data are collected by numerous groups, including academics, federal/provincial/territorial/Indigenous/municipal governments, non-profits, private industry, and

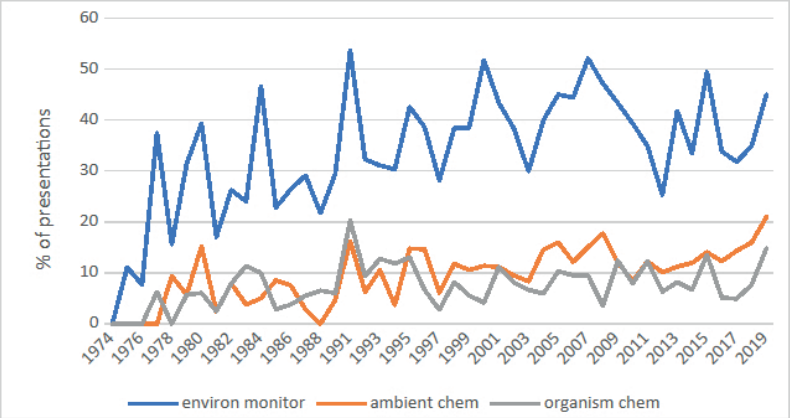

Figure 1: Percentage of ATW/CEW talks focused on environmental monitoring

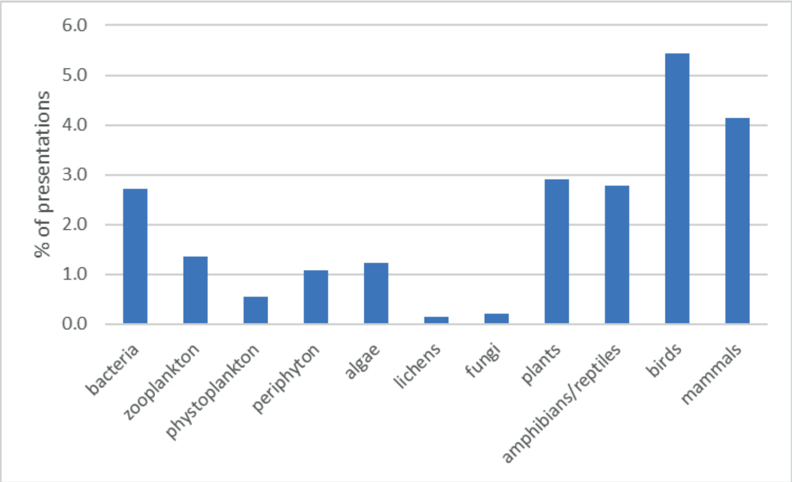

Figure 2: Frequency of focus of environmental monitoring presentations, other than talks focused on fish (48.3%) and benthic invertebrates (29.2%).

community groups. Despite the large amounts of data being collected, much of these data remains inaccessible. Even if data are made publicly available, they can be difficult to find and access in fragmented data repositories. When datasets can be found and accessed, they can still be difficult to join into larger datasets for analysis since there is no standard approach to data management. Consequently, scientists tend to spend more time finding, cleaning, and structuring data than they do on the important tasks of data analysis and interpretation. Initiatives such as the newly formed Canada Water Agency's development of a National Freshwater Data Strategy, are working to improve data management and sharing practices in the natural sciences (Environment and Climate Change Canada, 2024).

While we are experiencing a trend toward Open Data in the natural sciences, we must also ensure the transition is done well by upholding respect and authority for Data Sovereignty and Privacy. This means that not all data should be open and we must do our part to make sure we have the permissions we need for data-sharing before we go ahead and share it. All scientists should familiarize themselves with the First Nations principles of OCAP (ownership, control, access, and permission) (First Nations Information Governance Centre, 2025). Another helpful resource is Local Contexts, an organization that helps institutions and researchers share their data while respecting Indigenous data sovereignty (Local Contexts, 2025). Local Contexts has designed a labeling system (i.e., digital tags) that allows communities to express specific conditions for data sharing and future use. For example, labels can identify how the data can be used, verify that consent for sharing has been obtained, and identify the community who has authority over the data. These labels can be applied to a variety of data sources, including publications, datasets, and samples.

Summary

Since 1990, the proportion of talks focused on environmental monitoring has stabilized at just under 40% (Figure 1). Over the entirety of CEW, 33% of 2198 environmental monitoring presentations have focused on water or sediment chemistry. Of the remaining 1474 presentations, 48.3% have focused on fish and 29.2% on benthic invertebrates. Birds and mammals made up the next most common ecosystem components of focus (Figure 2). Chemical levels in organisms were the focus of 32.6% of presentations, with the next most common area of focus being physiological changes (20.0%). EEM-focused studies were

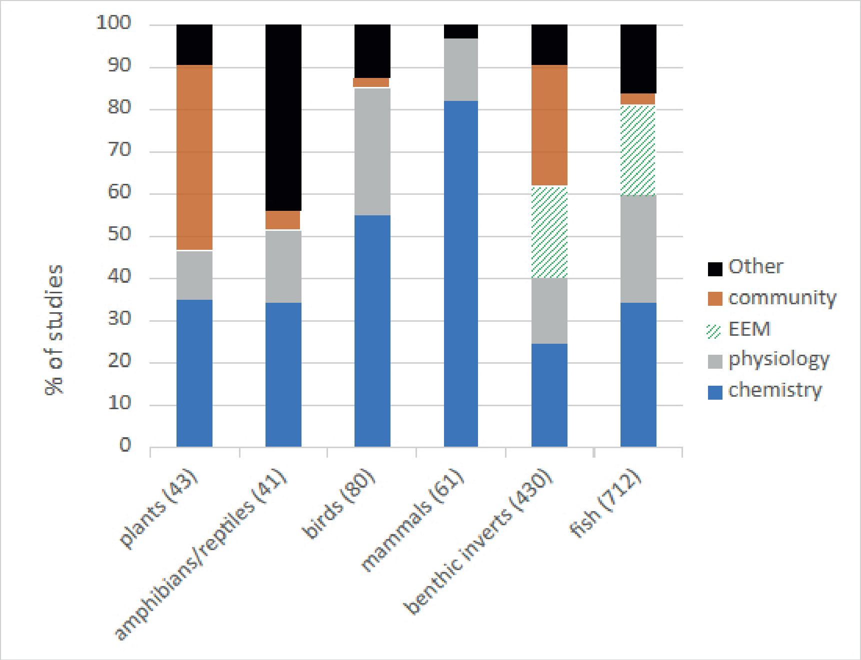

Figure 3: Focus of studies on most commonly used groups of organisms. The number in brackets represents the total number of environmental monitoring studies from 1974 to 2019.

restricted to benthic invertebrates and bivalves (21.6) of invert studies) and fish (21.2 %) (Figure 3).

References

Danielsen, F., Burgess, N.D., Balmford, A., Donald, P.F., Funder, M., Jones, J.P., et al. 2008. Local participation in natural resource monitoring: a characterization of approaches. Conservation Biology 23: 31-42.

Environment and Climate Change Canada. 2024. National Freshwater Data Strategy. Canada Water Agency [website]. Available online: https://www.canada.ca/en/environment-climate-change/services/water-overview/canada-water-agency/data-strategy.html

Follett, R., Strezov, V. 2015. An analysis of citizen science based research: Usage and publications patterns. PLoS ONE 10: e0143687.

First Nations Information Governance Centre. 2025. Understanding OCAP®. The First Nations Principles of OCAP® [website]. Available online: https://fnigc.ca/ocap-training/

Kanu, A., DuBois, C., Hendriks, E., Cave, K., Hartwig, K., Fresque-Baxter, J., Trembath, K., Kelly, E. 2016. Realizing the Potential of Community-Based Monitoring in Assessing the Health of Our Waters. Our Living Waters, Pooling Water Knowledge Working Group. 19 pp. Available online: http://awsassets.wwf.ca/downloads/realizing_the_potential_of_community_based_monitoring_in_assessing_the_health_of_our_.pdf

Khan, A., Litke, B., Risbey, C., Audet, K., Anderson, M., Docker, M. 2022. "Gone Fishing": Using environmental DNA (eDNA) and citizen science to assess the presence of stocked fishes in FortWhyte Alive's lakes. In Proceedings of the 48th Annual Canadian Ecotoxicity Workshop: October 2-5, 2022, Winnipeg, Manitoba. C. Rickwood, J. Anderson, M. Hanson, J.L. Rodríguez-Gil, S. Marteinson, J. Miller (Eds). p. 38. Available online: https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41269950.pdf

Kipp, A., Cunsolo, A., Gillis, D., Sawatzky, A., Harper, L. 2019. The need for community-led, integrated and innovative monitoring programmes when responding to the health impacts of climate change. International Journal of Circumpolar Health 78: 1517581.

Local Contexts. 2025. What is Local Contexts? Available online: http://localcontexts.org/

Reed, G., Brunet, N.D., Natcher, D.C. 2020. Can Indigenous community-based monitoring act as a tool for sustainable self-determination? The Extractive Industries and Society 7: 119529.

Sprague, J.B. 1969. Measurement of pollutant toxicity to fish I. Bioassay methods for acute toxicity. Water Research 3: 793-821

Roche, D.G., Granados, M., Austin, C.C., Wilson, S., Mitchell, G.M., Smith, P.A., Cooke, S.J., Bennett, J.R. 2020. Open government data and environmental science: a federal Canadian perspective. FACETS 5: 942-962.

Sprague, J.B. 1973. The ABC's of pollutant bioassay using fish. In Biological Methods for the Assessment of Water Quality. J Cairns, Jr Jr, KL Dickson (Eds) ISBN: 978-0-8031-0114-2

DOI: https://doi.org/10.1520/STP528-EB

Slave River and Delta Partnership. 2017. Slave Watershed Environmental Effects Program. Canadian Water Network. 7 pp. Available online: https://cwn-rce.ca/wp-content/uploads/2018/07/CWN-EN-SlaveRiver-2016-7Pager-Web.pdf

CHAPTER 9

Population and community responses in ecotoxicology: how have field assessments changed and where are they going?

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The challenge of complexity: Why study populations and communities?

Ecotoxicology requires the integration of knowledge across levels of biological organization to understand and predict contaminant effects. We aim to connect the mechanism of action of a contaminant at the biomolecular level with outcomes at the population, community, or ecosystem level. While laboratory toxicity tests are necessary to understand specific mechanisms of action and to characterize hazard, field assessments determine exposures and ecologically relevant effects of contaminants are needed to characterize risk. The overarching goal of ecotoxicology is to protect populations, communities, and ecosystems. As such, field assessments characterize endpoints such as exposures, species abundance, community biodiversity, and ecosystem function at sites with point and non-point source inputs of contaminants. Herein we describe how the field of ecotoxicology has advanced in recent decades, and end with some recommendations to address ongoing gaps in such studies.

Biomonitoring: The basis of field assessments in ecotoxicology

Biomonitoring is the oldest and most broadly applied method for ecotoxicological field assessments, dating back to the early 1900s. Biomonitoring is defined as the observation of biological organisms and their responses to environmental change. In aquatic environments this often involves the study of algae, benthic macroinvertebrates, and/or fishes. One of the most widely used and well-known biomonitoring programs in Canada is the Canadian

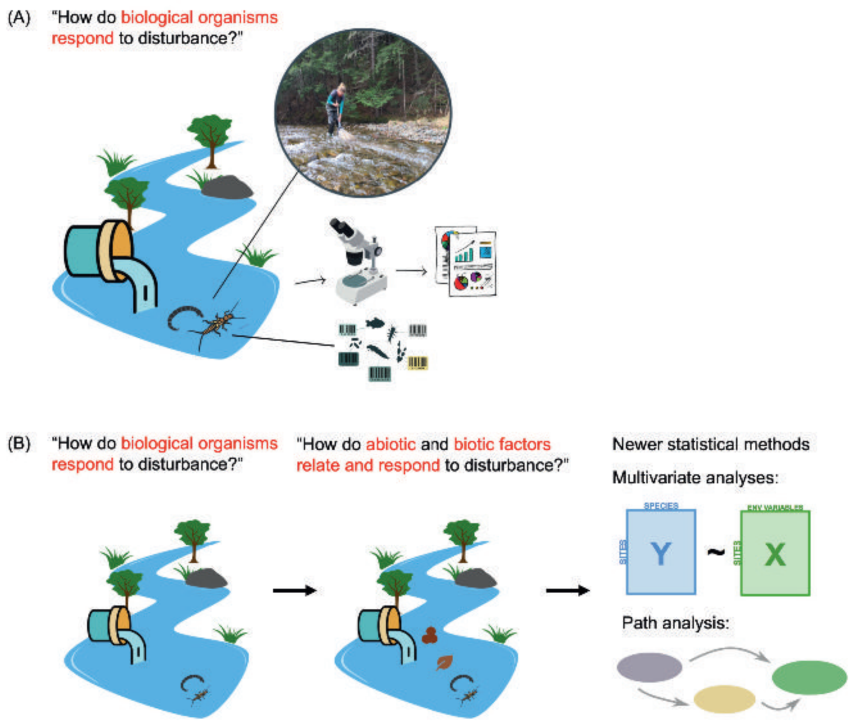

Figure 1: Overview of biomonitoring (A) which involves the collection of resident organisms (benthic macroinvertebrates, for example) from impacted and unimpacted sites. The organisms are identified and counted, and metrics are calculated to estimate population and community composition. More recently, DNA metabarcoding has been incorporated into biomonitoring programs to assist in the identification and counting of organisms. Over time biomonitoring has advanced (B) to incorporate abiotic and biotic factors that may relate to, and influence, organism responses to contaminants. These multi-metric and multivariate approaches are possible due to advances in statistical techniques.

Aquatic Biomonitoring Network (CABIN; canada.ca/en/environment-climate-change/services/canadian-aquatic-biomonitoring-network.html), established in 2006 by Environment and Climate Change Canada (ECCC). This program focuses on benthic macroinvertebrates because they are good indicators of water quality, are widespread and abundant, and are less mobile than fish, meaning they reflect the local environmental conditions. Different species also vary in their sensitivity to contaminants, allowing us to evaluate disturbance based on community composition. The standardized protocols are used at sites across the country to quantitatively collect benthic macroinvertebrate communities using kick nets, followed by identification and counts of all taxa present to calculate metrics like richness and abundance (Figure 1A). These traditional metrics are then used to evaluate the site condition relative to reference sites. More recently, this program has also included newer molecular techniques like DNA metabarcoding to assess biodiversity and community composition. These types of biomonitoring programs are invaluable for evaluating environmental health, assessing cumulative effects, and conducting environmental impact assessments.

Over time, biomonitoring has advanced to incorporate multi-metric and multi-variate approaches. Rather than asking “how do biological organisms respond to disturbance?” we now can ask “how do abiotic and biotic factors relate and respond to disturbance?”. For example, in addition to sampling macroinvertebrate communities, we can incorporate related abiotic factors like water chemistry or sediment deposition as well as ecosystem level processes like leaf litter decomposition (Figure 1B). These approaches are possible due to the development of more complicated statistical methods like multivariate analyses, which allow us to look at how a suite of environmental variables are related to community composition, or path analysis, which helps us to elucidate pathways and linkages among variables related to disturbance. Measuring several components of the ecosystem simultaneously has helped us to better understand and predict the influences of disturbance.

Mesocosms in ecotoxicology

One of the main challenges with field-based approaches is that it is difficult to assign causal relationships between toxicants and effects. This has led to the use of mesocosms in ecotoxicology. Mesocosms (also called “enclosures”) are artificially constructed ecosystems often designed to mimic the conditions in lakes, streams, or wetlands. They may vary in size and scale but generally have a

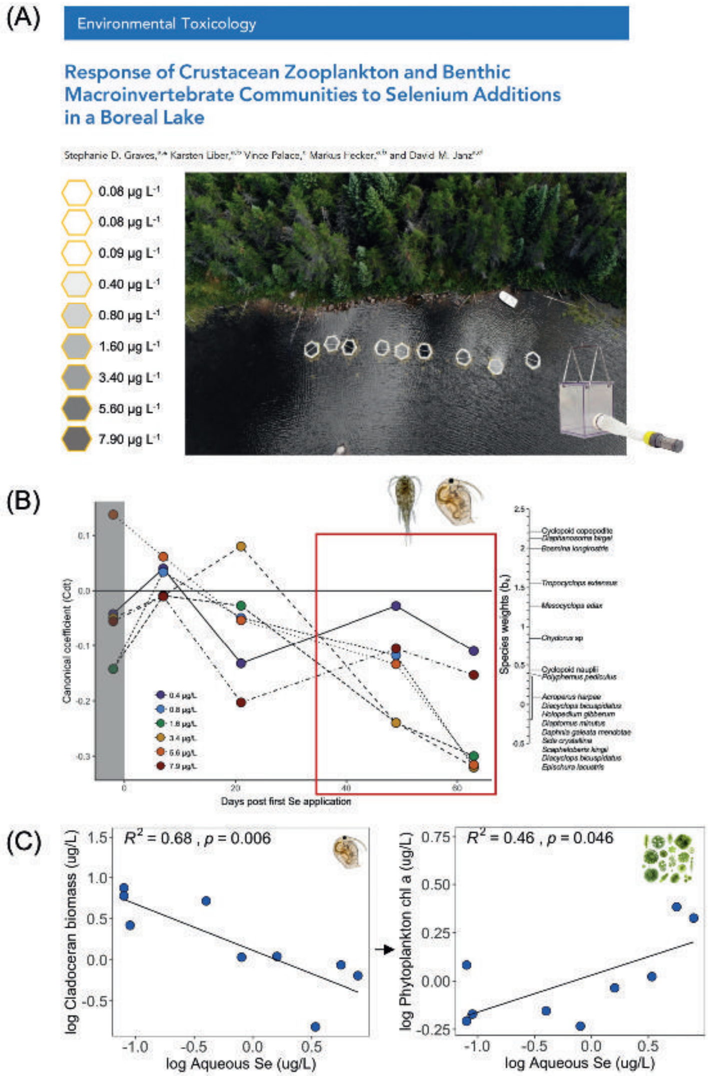

Figure 2: Mesocosm experimental design and set up by Graves et al. (2022) (A) and data reproduced with permission from Environmental Toxicology and Chemistry by Oxford University Press. Principal response curve of zooplankton communities exposed to increasing concentrations of aqueous selenium (B). Inverse relationship between Cladoceran biomass and aqueous selenium concentration at the end of the experiment (C), which corresponded to a positive relationship between phytoplankton chlorophyll a and aqueous Se concentration (D).

common objective: to incorporate ecological realism while maintaining control over exposure concentrations, environmental conditions, and replication. Mesocosms can be used to assign causal relationships under realistic conditions and incorporate indirect effects like species interactions and predator-prey relationships that are difficult to study under field conditions.

Mesocosm use in ecotoxicology began in the late 1970s and often focused on the effects of pesticides on non-target organisms using in situ enclosures in lakes, or ex situ artificial ponds inoculated with water, sediment, and associated biota. In one of the earliest studies in Canada, 125,000-L in situ enclosures in a mesotrophic lake were used to study the effects of permethrin on zooplankton communities (Kaushik et al. 1985). In this study an ANOVA design with control, low, and high concentrations of permethrin in triplicate were used. The zooplankton community was sampled pre- and post-permethrin addition for several weeks throughout the open-water season and the zooplankton were identified and enumerated to determine density of each species and diversity of the community. Not only was permethrin exposure associated with declines in the density of some zooplankton taxa, but there were also indirect effects of permethrin on predator-prey and competition interactions within the zooplankton community that could not be observed in the laboratory (Kaushik et al. 1985). Therefore, early mesocosm studies proved valuable for measuring how several naturally occurring taxa respond to chemical treatments simultaneously, and identifying how community composition (i.e., diversity and taxa richness) changes in response to contaminants. This community-level testing approach was also highlighted for being able to incorporate ecological factors, such as species interactions, into ecotoxicity studies, and identify indirect effects of contaminants such as predator prey and competition interactions.

Today, mesocosms are widely used to assess the fate and effects of diverse contaminants under field conditions. For example, in 2017, in situ enclosures in a lake were used to assess the effects of selenium on zooplankton and benthic macroinvertebrate communities (Figure 2A). A regression approach was used, rather than the ANOVA design often applied in early studies, because it gives more information about the concentration-response relationship of communities and contaminants. A range of aqueous selenium concentrations were added to mesocosms to study changes in density and community composition of invertebrates. One of the biggest changes to mesocosm experiments over time is the analysis of these data using a multivariate technique called principal response curves (PRC) – a method specifically designed to analyse mesocosm community effects data (Van Den Brink and Braak 1999). The PRC represents communities according to treatment (shown as different colours in Figure 2B) over time relative to the control communities (represented by the horizontal black line in Figure 2B). The PRC can be interpreted as communities more different from the control being further from the horizontal line and the species weights in the PRC show which taxa have the biggest influence on the overall response of the community. In this example, the PRC showed that community composition was significantly altered in all treatments above 0.4 µg Se/L. Such changes were mostly due to the sensitivity of Cladocerans: there was a significant decrease in Cladocera biomass with increasing Se at the end of the experiment (Figure 2C). Interestingly, this decrease in zooplankton biomass corresponded to increases in phytoplankton chlorophyll a (Figure 2D), suggesting a potential change in grazing pressure with the loss of some zooplankton taxa. Like early mesocosm studies, this experiment was used to identify the community-level effects of selenium, differences in sensitivity among naturally occurring taxa, and incorporated and identified potential consumer-producer dynamics. These results demonstrate that mesocosms continue to be valuable in identifying community-level effects under field conditions and elucidating indirect effects that cannot be studied in the laboratory.

Whole lake experiments in ecotoxicology

While mesocosm studies extend our knowledge on toxicant impacts beyond the laboratory, they too are limited as experiments are typically shorter term (weeks to months) and do not include highly mobile and long-lived species such as top predator fishes. Whole ecosystem experiments are the 'gold standard' for understanding both the direct and indirect effects of chemical stressors on aquatic ecosystems, and several such studies have been done at the globally unique International Institute for Sustainable Development – Experimental Lakes Area (IISD-ELA) in northern Ontario, Canada. The IISD-ELA is a group of 58 lakes and their watersheds that have been used for high impact experiments on water quality issues of concern since it was established in 1968. The advantage of this research station is that the lakes exist in undisturbed watersheds and experiments are free from the confounding factors (e.g., habitat loss) often associated with field biomonitoring. The general design of these whole-ecosystem studies includes baseline sampling of water chemistry through communities in the experimental lake, often over multiple years, several summers of additions of the chemical of interest to achieve a target concentration for exposures, and concurrent assessments of the chemical and biological responses to the manipulation. At the same time, monitoring is done in reference lakes to understand natural variability in these communities and their abiotic environments. The long-term nature and scale of these experiments provides a holistic assessment of how contaminants impact generations of aquatic species, and almost always lead to insights that could not be obtained from smaller-scale studies, including those in mesocosms.

The first whole-lake experiment on chemical stressors at the IISD-ELA started in 1974, and was motivated by the acidification of fresh waters by acid rain (Schindler et al. 1985, Mills et al. 2000). After two years of baseline study, Lake 223 was experimentally acidified using sulfuric acid to decrease the pH from 6.5 to 5.0 over 8 years and then the lake was allowed to recover to its original pH over 13 years. This was the first experiment to unequivocally demonstrate the value of whole-lake studies in ecotoxicology. Monitoring in Lake 223 and reference systems revealed a greater sensitivity of fish populations to the acidification of surface waters as recruitment failures occurred at higher pH than predicted based on lab studies, and some small-bodied fishes (fathead minnow and slimy sculpin) and the crustacean Mysis went extinct (Figure 3A). For the top predator lake trout, these changes in its prey led to declines in fish condition and survival and a much lower population size even after the lake's pH had recovered. In contrast to the lake trout, the population of fathead minnow recovered almost fully by the end of the study. These species' trajectories during acidification and recovery, in combination with the lower-trophic-level and chemistry data, unequivocally demonstrated that this chemical stressor has long-term impacts on the diversity and structure of aquatic communities as it has not yet recovered to its original state.

However, many of the mechanisms underpinning the responses of the ecosystem to acidification remain unknown given that this study did not include basic biochemical- (e.g., enzyme) through individual-level (e.g., histological) assessments for the fishes, and the populations were not assessed genetically to

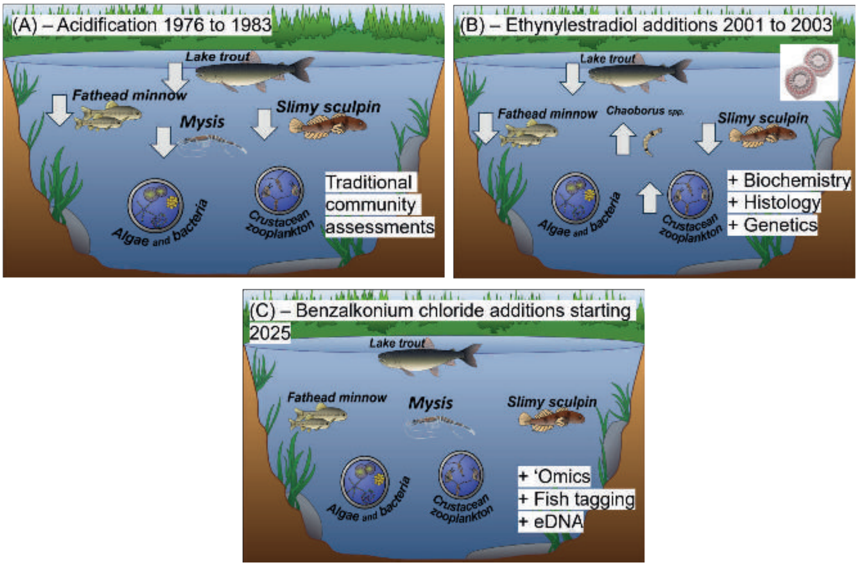

Figure 3: Responses of food webs to the (A) acidification of a lake to pH 5.0 (Mills et al. 2000), (B) additions of the potent estrogen ethynylestradiol (Kidd et al. 2007, 2014), and (C) additions of the antimicrobial benzalkonium chloride (additions starting in 2025). All studies incorporated traditional measures of taxonomy and relative abundance of plankton through fish communities, with the newer experiments also including molecular and tissue-level responses, population genetics, 'omics and behaviours (fish tagging), allowing for a more advanced understanding of responses to toxicants across levels of biological organization.

determine whether recovered individuals were from in-lake production or immigration. Such tools were not available during the earlier years of this study.

More recent whole-lake studies at IISD-ELA have profited from molecular through population approaches that advance our understanding of contaminant effects across different levels of biological organization; one such study involved additions of the synthetic estrogen used in the birth control pill, 17a-ethynylestradiol (EE2) (Kidd et al. 2007, 2014) (Figure 3B). This experiment was done in response to the growing evidence that male fishes were becoming feminized in municipal wastewater-impacted waters due to the presence of estrogenic chemicals like EE2, and it was unclear whether this feminization was affecting the sustainability of fish populations. Three summers of EE2 additions (target 5 ng/L) to Lake 260 at IISD-ELA led to elevated production of the egg yolk protein precursor vitellogenin - both its protein and mRNA, delays in gonad development, and a near extinction of the fathead minnow from the lake. This combination of endpoints unequivocally demonstrated that the feminization of male fishes through biochemical mechanisms can result in a decreased abundance of a wild fish population. The direct effects of the EE2 on the fathead minnow occurred in parallel with declines in lake trout abundance and increases in zooplankton and benthic invertebrate biomass, responses believed to be indirect effects due to the trophic cascades caused by declines in this minnow. Recovery of the ecosystem was also examined and here the study benefited from genetic (microsatellite) analyses to show that the fathead minnow recovered post chemical amendments through in-lake reproduction rather than immigration from a nearby lake (Blanchfield et al. 2015). In contrast to the acidification study, the EE2 experiment benefited from the use of both traditional assessment approaches (e.g. taxonomy) and newer approaches to understand the mechanisms underpinning the population crash and recovery of the fathead minnow and recovery.

Recent and current whole-ecosystem experiments at IISD-ELA continue to address water quality issues of current concern including mercury, microplastics, cyanobacterial blooms, and the disinfectants benzalkonium chloride (Figure 3C) (www.iisd.org/ela). As new methods to link contaminant exposures to population and community responses grow, so too will the value of these experiments. Additional measures like the ‘omics described below will provide earlier warnings of contaminant effects as well as a broader suite of

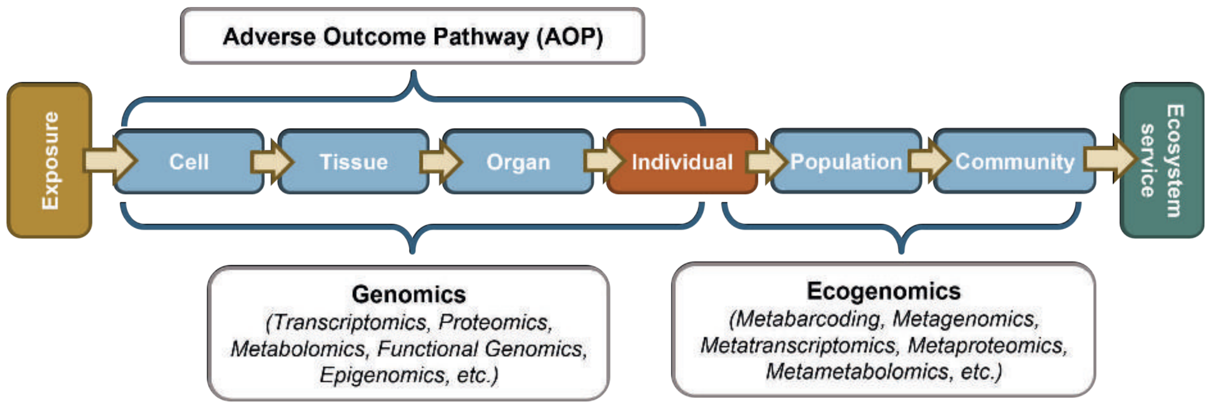

Figure 4: Omics technologies to assess changes across all levels of biological organization in ecotoxicology studies.

responses than has previously been possible. New technologies available for tagging fish will improve our understanding of how contaminants change their behaviours such as habitat use. Similarly, eDNA techniques will complement and likely expand the traditional community assessments that have been used over the past five plus decades of ecotoxicology research at IISD-ELA.

New approaches in ecotoxicology

In recent decades, advances in molecular biology, especially 'omics technologies, are becoming key tools for environmental monitoring and assessments in ecotoxicology. These comprehensive, high-throughput approaches, including the study of genomes (genomics), gene expression (transcriptomics), protein expression profiling (proteomics), or metabolite profiling (metabolomics), expand the toolbox for scientists to detect and link changes across multiple levels of biological organization, from molecular and cellular functions to whole organisms, populations, and communities (Figure 4) (Esser et al. 2024). By providing a holistic view of how organisms respond to environmental stressors, omics approaches reveal mechanistic insights into toxicity that often remain hidden when using traditional assessment methods. Additionally, omics technologies are employed to detect early signs of ecological disturbance and to identify novel biomarkers of exposure and effect.

One of the most promising areas lies in the development and refinement of conceptual frameworks designed to trace biological disturbances. Among these, Adverse Outcome Pathways (AOPs), introduced in the early 2010s, have become a central approach that integrates omics techniques to better connect molecular-level changes to observable outcomes (Ankley et al. 2010, Kramer et al. 2011). AOPs are distinct in their "bottom-up" approach, starting at the molecular level (i.e. molecular initiating events; MIE) within individual organisms and progressively building toward predictions of adverse effects at higher biological levels. This is achieved through the integration of probabilistic and predictive modeling techniques, such as logistic matrix models and Bayesian frameworks. These pathways therefore provide a structured approach for linking mechanistic data to ecological and regulatory endpoints, helping to translate complex molecular signals into meaningful predictions of risk. Consequently, AOP frameworks have gained recognition in regulatory science for their ability to efficiently link toxicological mechanisms with standardized endpoints critical to regulatory evaluations. Despite this strength, a considerable limitation lies in its

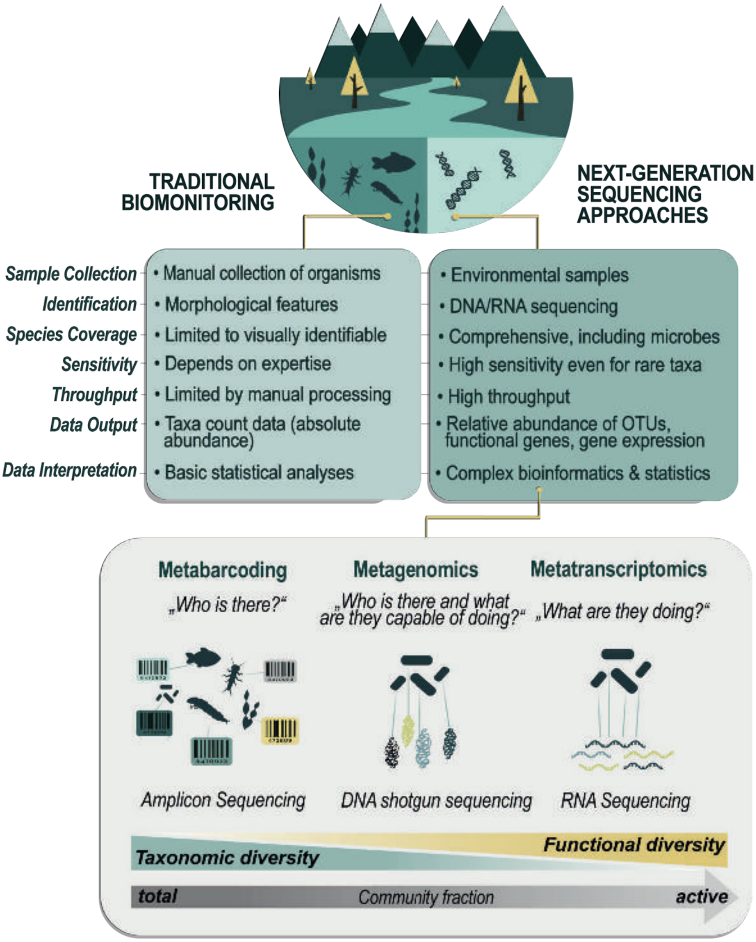

Figure 5: Comparison of traditional biomonitoring methods and next-generation sequencing approaches.

emphasis on individual or sub-individual level outcomes. While this focus aligns well with regulatory priorities, it restricts its applicability for capturing effects at higher biological levels. Although promising approaches like population modeling based on individual-level endpoint data have emerged to predict community or population responses (e.g., Miller et al. 2013), significant challenges persist, particularly in capturing indirect effects, such as species interactions, and addressing the simultaneous influence of multiple stressors, limiting the accuracy of these models in real-world applications.

However, when applied effectively omics technologies offer the potential to qualitatively and quantitatively measure changes across all levels of biological organization, from molecular and cellular levels to tissues, individuals, populations, and communities (Figure 4). Approaches like DNA metabarcoding, metagenomics, and metatranscriptomics now make it possible to assess the composition, functional potential, and activity of entire communities (Figure 5). These methods also enable the inclusion of previously overlooked groups, such as microbial communities, which serve as sensitive indicators of environmental change.

Building on these advanced methods, field-based approaches like environmental DNA (eDNA) metabarcoding have become increasingly popular in field assessments (Ruppert et al. 2019). As one of the most applied NGS technique in the field to date, eDNA metabarcoding allows for the detection and identification of diverse taxa based on genetic markers, directly from environmental samples. Compared to conventional biomonitoring techniques, DNA metabarcoding brings several key advantages. It allows for the detection of a broader range of taxa, including cryptic, microscopic, or larval forms that are often missed in traditional surveys. Moreover, it reduces reliance on taxonomic expertise, increases throughput, and enhances reproducibility. It allows the detection of organisms without prior knowledge and can be applied in locations where traditional surveys are impractical. While traditional methods remain essential, particularly for validating ecological interpretations and understanding functional roles, metabarcoding provides an efficient and complementary layer of biological insight. However, as with any emerging field, there are concerns about the methodology of eDNA metabarcoding. Each stage of the process can potentially affect the outcomes, and because these results may influence critical conservation decisions, it is essential to refine and standardize the methods to ensure their reliability and accuracy.

Ultimately, the adoption of omics techniques in ecotoxicological biomonitoring offers a more comprehensive and sensitive means of assessing ecosystem health. These tools expand our ability to evaluate biodiversity across all domains of life, including microorganisms that are integral to ecosystem functioning but rarely accounted for in standard assessments. By coupling taxonomic resolution with functional endpoints, these methods not only improve our understanding of how communities respond to stressors but also illuminates the ecological consequences of those changes. As these approaches continue to evolve, they promise to deepen our ability to monitor, predict, and manage the impacts of human activities on natural systems.

Future priorities for field-based assessments in ecotoxicology

As the field of ecotoxicology continues to develop, it is becoming increasingly clear that several foundational aspects of the discipline must evolve to meet emerging challenges such as the interactions of climate warming with the greater diversity of environmental contaminants. Moving forward, we must continue to critically reflect on how we study, interpret, and apply ecological information in the context of contamination. This includes reassessing experimental approaches, integrating new tools, and broadening the ways we define and value ecosystem health. Ecotoxicology relies upon the integration of knowledge across different levels of biological organization to answer the question: What are the pathways that lead from pollutant exposure to ecosystem level impacts? This integration is essential for understanding and predicting the effects of contaminants and environmental stressors on ecological systems, which is the primary goal of ecotoxicology and supports the protection of populations, communities and ecosystems. Only by identifying the underlying pathways and mechanisms can we fully grasp how various substances interact with biological systems across multiple levels, from individuals to entire ecosystems. The following are key areas that we believe require attention to continue to advance ecotoxicology in meaningful and relevant directions.

1. **Incorporating realism and complexity.** A central challenge in ecotoxicology remains the gap between controlled experimental studies and the complexities of ecosystems. While laboratory experiments provide essential mechanistic insights, they often fail to capture indirect effects, delayed responses of longer-lived species, or recovery following exposure. Future

research should adopt more ecologically relevant designs that consider indirect effects, mixture toxicity, interacting stressors, and temporal dynamics. Incorporating environmental variability into studies and modeling, such as fluctuating temperatures, flow regimes, or background nutrient levels, will help bridge experimental findings with field observations. This shift is critical to improve the predictive power of ecotoxicological assessments and better inform environmental management.

2. Expanding data resources and analytical tools. As high-throughput methods become more accessible, reference databases are rapidly expanding. However, the increasing volume and complexity of ecological data demand equally sophisticated analytical tools. There is a growing need for approaches that can effectively interpret large, multidimensional datasets and translate them into ecologically meaningful insights. Functional and trait-based frameworks offer promising avenues for detecting biological shifts and understanding how changes in community structure may affect broader ecosystem processes. Fostering analytical innovation will be essential for making full use of technological advancements and linking biological responses to ecological function.

3. Connecting outcomes to ecosystem services. Future ecotoxicological assessments should consider how contaminants influence ecosystem functions that support biodiversity and human well-being. Understanding the links between species-level impacts and ecosystem services like nutrient cycling, water purification, and biodiversity will help emphasize the ecological significance and implications of observed changes to those with the abilities to effect change, us. By aligning ecological assessments with the assessment of ecosystem services, researchers can strengthen justifications for protective actions and foster more sustainable, informed decision-making.

4. Linking western science with Indigenous knowledge. Lastly, ecotoxicology must also evolve to reflect a more inclusive understanding of ecosystems, by recognizing Indigenous knowledge. Traditional ecological knowledge in Indigenous communities, rooted in generations of close observation and cultural relationship with land and water, offers unique and valuable perspectives on long-term environmental change. These insights capture subtle behavioural or ecological shifts long before they are detected through conventional scientific monitoring. Future research should prioritize respectful collaboration with Indigenous communities, braiding knowledge systems in ways that uphold sovereignty and foster mutual learning. This approach enriches scientific inquiry while supporting more equitable and holistic environmental stewardship.

References

Ankley, G. T., R. S. Bennett, R. J. Erickson, D. J. Hoff, M. W. Hornung, R. D. Johnson, D. R. Mount, J. W. Nichols, C. L. Russom, P. K. Schmieder, J. A. Serrrano, J. E. Tietge, and D. L. Villeneuve. 2010. Adverse outcome pathways: A conceptual framework to support ecotoxicology research and risk assessment. Environmental Toxicology and Chemistry 29:730–741.

Blanchfield, P. J., K. A. Kidd, M. F. Docker, V. P. Palace, B. J. Park, and L. D. Postma. 2015. Recovery of a wild fish population from whole-lake additions of a synthetic estrogen. Environmental Science & Technology 49:3136–3144.

Esser, M., M. Brinkmann, and M. Hecker. 2024. Solving freshwater conservation challenges through next-generation sequencing approaches. Environmental Science: Advances 3:1181–1196.

Graves, S. D., K. Liber, V. Palace, M. Hecker, and D. M. Janz. 2022. Response of crustacean zooplankton and benthic macroinvertebrate communities to selenium additions in a boreal lake. Environmental Toxicology and Chemistry 41:95–107.

Kaushik, N. K., G. L. Stephenson, K. R. Solomon, and K. E. Day. 1985. Impact of permethrin on zooplankton communities in limnocorrals. Canadian Journal of Fisheries and Aquatic Sciences 42:77–85.

Kidd, K. A., P. J. Blanchfield, K. H. Mills, V. P. Palace, R. E. Evans, J. M. Lazorchak, and R. W. Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. Proceedings of the National Academy of Sciences 104:8897–8901.

Kidd, K. A., M. J. Paterson, M. D. Rennie, C. L. Podemski, D. L. Findlay, P. J. Blanchfield, and K. Liber. 2014. Direct and indirect responses of a freshwater food web to a potent synthetic oestrogen. Philosophical Transactions of the Royal Society B: Biological Sciences 369:20130578.

Kramer, V. J., M. A. Etterson, M. Hecker, C. A. Murphy, G. Roesijadi, D. J. Spade, J. A. Spromberg, M. Wang, and G. T. Ankley. 2011. Adverse outcome pathways and ecological risk assessment: Bridging to population-level effects. Environmental Toxicology and Chemistry 30:64–76.

Miller, D. H., J. E. Tietge, M. E. McMaster, K. R. Munkittrick, X. Xia, and G. T. Ankley. 2013. Assessment of status of white sucker (*Catostomus commer*soni) populations exposed to bleached kraft pulp mill effluent. Environmental Toxicology and Chemistry 32:1592–1603.

Mills, K. H., S. M. Chalanchuk, and D. J. Allan. 2000. Recovery of fish populations in Lake 223 from experimental acidification. Canadian Journal of Fisheries and Aquatic Sciences 57:192–204.

Ruppert, K. M., R. J. Kline, and M. S. Rahman. 2019. Past, present, and future perspectives of environmental DNA (eDNA) metabarcoding: A systematic review in methods, monitoring, and applications of global eDNA. Global Ecology and Conservation 17:e00547.

Schindler, D. W., K. H. Mills, D. F. Malley, D. L. Findlay, J. A. Shearer, I. J. Davies, M. A. Turner, G. A. Linsey, and D. R. Cruikshank. 1985. Ecosystem stress: the effects of years of experimental acidification on a small lake. Science 228:1395–1401.

Van Den Brink, P. J., and C. J. F. T. Braak. 1999. Principal response curves: Analysis of time-dependent multivariate responses of biological community to stress. Environmental Toxicology and Chemistry 18:138–148.

Chapter 10

Health of the Ocean: The critical intersection of marine ecotoxicology and human health research and action in an era of climate change.

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Introduction

The global ocean in the 21st century faces many threats to its biodiversity and component ecosystems, as humans (now numbering more than 8 billion) continue to use the ocean and its living and non-living resources. Knowledge from the newly-maturing field of marine ecotoxicology (MARTOX) now helps to protect marine organisms and ecosystems, and also aids in the detection of threats to and protection of the health and well-being of people, all of this in this critical era of unprecedented, anthropogenic ally driven climate change.

This paper is a perspective on the intersection of marine ecosystem health (otherwise known as health of the ocean or HOTO), ocean and human health (otherwise known as OHH), and the future challenges for MARTOX. It results from a unique partnership of two scientists with quite different but complementary marine science backgrounds and experiences. We taught together for many years in an international MARTOX course in Bermuda, enlarging our view of ocean health and the various issues that the oceans face through recognition of the value of interdisciplinary science.

The paper highlights key information and principles of HOTO and MARTOX – "identifying what we do to the oceans that is harmful"; and of OHH

– "what do the oceans do for us, and what are the threats to us from human activities in the ocean". It is evident that these fields are interconnected in important ways (Knap *et al.* 2002, Bowen *et al.* 2014, among others). Marine pollutants damage organisms in many ways (Blasco *et al.* 2016) and health practitioners recognize that "pollution is the largest environmental cause of disease and death in the world today" (Landrigan *et al.* 2020).

Given the CEW 2024 conference theme of current research and synthesis in the broad field of ecotoxicology, we present an overview on ocean health (HOTO and OHH), some of the latest developments in MARTOX, and some core questions to guide future research in marine ecotoxicology.

Background

Humans currently live in an environmental emergency ward, largely due to a burgeoning human population, the wide use of industrial chemicals and petroleum products, (especially plastics) increased degradation of natural habitats, and with many millions of people living along vulnerable coastlines in an era of climate change (Wells 2023). No aquatic ecosystem illustrates this emergency better (or worse!) than the ocean. Although progress has been made to identify and control many problems, it often takes countries and international governmental and non-governmental bodies far too long to address and resolve the many problems affecting both marine ecosystems and their biodiversity, and humans with their many connections to the sea. It takes human illness, sometimes deaths (from infectious pathogens, or algal toxins such as domoic acid and red tide dinoflagellates), or the threat of catastrophe (CFCs and the ozone layer) to move politicians and bureaucracies to respond rapidly with interventions; they may include bans of certain chemicals, coastal fisheries and habitat closures, pollutant regulations and guidelines, and controls of specific harmful activities (e.g., ocean dumping). Delay in such situations demonstrates failure to prevent or mitigate potential threats that have often been identified years earlier.

It is well worth noting that as early as 1938, the famed American marine biologist and writer Rachel Carson was already curious about ecological relationships between humans and the natural world and also interested in habitat pollution and environmental health, this while working on her first book Under the Sea Wind, published in 1941 (Lear 1997). She recognized human influences on coastal environments and continued to write about it, as did others at the time (e.g., Jacques Cousteau). Going forward into the 1970s and beyond - marine pollution problems have been described and discussed repeatedly over the 50 years of the ATW/CEW series of workshops in Canada, meetings that started in 1974 and that predate SETAC`s excellent annual conferences by six years.

During the final decade of the last century, the plight of the oceans from pollution was recognized formally as being linked with human health threats. The United Nations Rio Summit Conference in 1992 gave birth to Agenda 21 – a prescription for saving the oceans as well as the rest of the planet. Following that meeting, marine ecotoxicologists and health scientists (as well as those from other ocean disciplines) came together for the first time in 1999 in Bermuda to establish the meta-discipline of "Oceans and Human Health" or OHH (Knap *et al.* 2002, Depledge 2024). While the many connections between ocean health (HOTO) and human health (OHH) are now well recognized, the precise contributions and importance of marine ecotoxicology to both fields have not been discussed in any depth, nor new key questions identified with an eye to the future. This is the goal of this paper.

In brief, the paper covers these topics:

- Definitions and main messages.
- Key threats to ocean health (HOTO).
- Key threats to human health (OHH).
- The current status of marine ecotoxicology (MARTOX).
- Key connections between these fields.
- Contributions of marine ecotoxicology and new questions that ecotoxicologists can/should address.

One of us (Wells) has been associated with the ATW-CEW throughout its history (Parker *et al.* 1977, Wells 2009, 2016, Wells and Addison 1985, Wells and Doe 2014). The important connections of ocean health to human health have been identified comprehensively by Depledge (see references, especially Depledge 2016, 2018, 2024, and pers. comm.). This paper reflects a long history working with various colleagues on marine pollution problems, from industrial effluents to oil pollution to contaminants in mussels, some of which have been reported at the annual ATW-CEW workshops over the years, all now encapsulated under the broad header of "ocean health". It points to the importance of aquatic toxicology and ecotoxicology, and the need to consider how these scientific fields contribute broadly to the protection of our coastal and ocean spaces, its biodiversity, and its human inhabitants.

Definitions and Main Messages

Clarification of the terms is important to any discussion of ocean health.

Ocean health or health of the ocean (HOTO) - there is no single definition of ocean health or ecosystem health, and one that directly links it to the practice of marine ecotoxicology. The UN IOC (Intergovernmental Oceanographic Commission)'s operational definition is "the condition of the marine environment from the perspective of adverse effects caused by anthropogenic activities, and considering the contemporary state of the ocean, prevailing trends, and a prognosis for improvements"(Health of the Ocean Panel, UNESCO, 1996). Ocean health encompasses the concept of ecosystem health, a metaphor that represents the condition of an ecosystem measured using various appropriate indicators, usually in combination.

Oceans and human health (OHH) – it considers the human health aspects of contact in various ways with the ocean. Human health is defined as "a state of complete physical, social and mental well-being, and not merely the absence of disease or infirmity" World Health Organization (Knap *et al.* 2002). The goal of an OHH program should be "early detection of potential marine-based contaminants, with the ultimate outcome being the preservation of natural resources and prevention of associated human illness" (Knap *et al.* 2002). The development and application of biomarkers (measurable indicators of some biological state or condition) is a critical component of such a program. There has been considerable activity and progress in this field since 2000, especially in the UK, in the USA with its OHH centres of excellence, and in mainland Europe (European Marine Board, Watson-Wright 2022). This progress is best shown by the books of Bowen *et al.* (2014) and Fleming *et al.* (2023).

Marine ecotoxicology (MARTOX) - is the field of study of the fate and effects of chemical and physical pollutants in the marine environment (from estuaries to coastal and offshore waters), marine pollution being defined by GESAMP (Windom 1991) and the 1982 United Nations Convention on Law of the Sea (UNCLOS), as "the introduction by man, directly or indirectly, of substances or energy into the marine environment, which results or is likely to result in such deleterious effects as harm to living resources and marine life" (UNCLOS 1982). Assessment of pollution includes laboratory studies, both basic and applied, microcosm and mesocosm studies, and field monitoring in intertidal and subtidal waters, using a variety of techniques, from selected indicator organisms to electronic tags, especially in more recent years using various omic techniques (see later section).

The main messages of this paper are:

- The threats to ocean health and human health are all taking place against a very active backdrop of climate change.
- We need to continually monitor and assess the quality of the marine environment using the tools of marine ecotoxicology while emphasizing the connections between marine ecosystem health and human health, to ensure timely action by policy and decision makers.
- Marine ecotoxicology has become quite sophisticated with new methodologies originating from various biological disciplines, especially molecular biology and genomics.
- In our view, there should be much closer collaboration between marine scientists in this field and health professionals.
- This linkage is a prerequisite to encouraging faster action by policy and decision makers in governments, as the protection of people usually takes priority over the protection of marine biodiversity.

Key threats to ocean/marine ecosystem health

The core scientific literature clearly shows that the key threats are fishing and overfishing (biomass removal), side effects (feed, chemicals) of ocean-based aquaculture, loss of habitats and biodiversity, climate change (with many variables at play), pollution primarily from land-based sources, e.g., effluents, plastics, litter, POPs, noise, etc., (Fig. 1), coastal development, and their interactions and confounding factors as these threats or pressures do not occur alone in many cases.

Land-based pollution of the sea, especially from untreated or partially treated sewage, is common and while well-recognized as a threat, it is only slowly being addressed, even in developed countries. Marine debris has received more attention in recent decades since the huge ocean gyres of floating debris were observed in many locations, e.g., the Great Pacific Garbage Patch, late in the 20th century. Plastics and micro-plastics pose a threat/risk to both marine organisms and humans who eat seafood. Along coastlines, coastal erosion is increasing in many places, enhanced by storms strengthened by climate change. There are clear linkages between ocean health, climate change, and all ocean inhabitants, including us (Fig 2.)

Figure 1: Ocean Pollution - some of the primary sources.

The multi-dimensional and complex nature of ocean health is also shown by the recent development and application of the OHI (Ocean Health Index) (Halpern *et al.* 2012) (Fig 3). It has 10 public goals, covering all ocean uses, and is an attempt to comprehensively evaluate and rank ocean health taking into account ocean biota, ecosystems, and the many ways humans interact with and use the ocean. This is a good introduction to the next topic, how human health is linked to and dependent upon a healthy ocean and its biodiversity.

Key threats to human health from the ocean

Most recently, Borja *et al.* (2020) stated that "the growing evidence demonstrates that the health of the ocean and the health of humans have always been and continue to be inextricably linked". This is supported by Reamer (2022) who stated that "there is a considerable literature demonstrating linkages between ecological systems and the determinants of human health and well-being". These are messages that other investigators, notably Knap *et al.* (2002), Bowen *et al.* (2014), and Depledge (many papers, such as Depledge 2024) have been making for at least 25 years (Fig. 4). It is timely, but way overdue, that there is now a United Nations Ocean Decade (2021-2030) with the theme of ocean research, ocean literacy, and ocean health.

At a Monaco Conference on OHH in December, 2020, the risks to human health from events and changes in the ocean were described in detail. Climate change, marine pollution, harmful algal blooms, coastal flooding, extreme weather events, and exposure to contaminated waters causing infectious diseases were highlighted. Demographic changes with more people living along the coasts are leading to more risks and more illnesses, drownings, and work related deaths. At the same time, there are many human benefits for the sea, from seafood to transportation to leisure pursuits. Unquestionably, the ocean and human linkages are many (Fig 5), vital, and often at risk, hence the effort to study these linkages and make the case to policy and decision makers of the need to protect and manage the coastal waters and oceans urgently and comprehensively (Depledge 2024). With a rapidly growing human population, delay is not an option if people are to be protected.

Marine ecotoxicology (MARTOX) and a need to broaden its scope

The field of aquatic toxicology, developing since the 1950s (Rand 1995, Rand *et al.* 1995) and given a firm foundation in the late 60's by John Sprague's

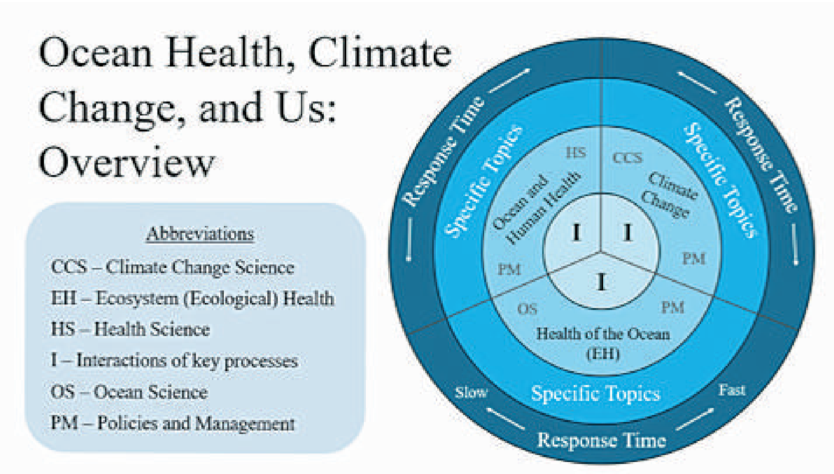

Figure 2: Interactions between ocean health and climate change, and the importance of timely response.

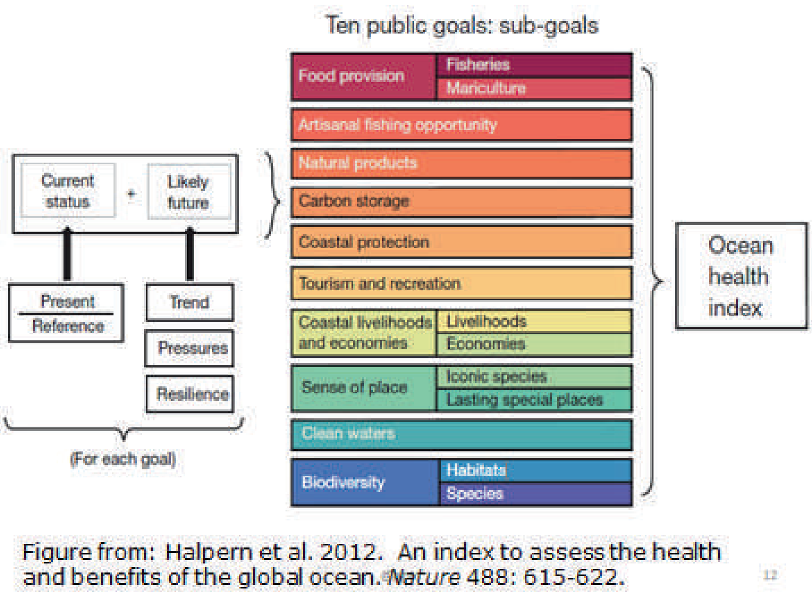

Figure 3: Goals of the ocean health index.

three classic papers, has had in recent decades a subcomponent addressing the effects of chemical contaminants and physical stressors in the oceans, namely marine ecotoxicology. Most of the research and applied studies involved test methods development (e.g. Environment Canada - Taylor and Scroggins 2013, Taylor *et al.* 2013), single species testing, and chemical and biological effects monitoring. New single species tests proliferate (note ECCC's many biological tests, the latest being with copepods and urchins) and new approaches, even at the lowest taxonomic level with communities of organisms, are continually being proposed (e.g., Wells 2013).

In situ monitoring is critical, as in our USA-Canada GOMC Gulfwatch program (samples are archived for further analyses when funding permits, note Elskus *et al.* 2020). Such marine bivalve monitoring programs are conducted in many countries and are becoming increasingly sophisticated (Chahouri *et al.* 2023).

A very large primary literature and many recent books cover the advancements in aquatic toxicology and ecotoxicology (e.g., Campbell *et al.* 2022, Di Giulo and Hinton 2008, Ferard and Blaise 2013, Hoffman *et al.*, 2003, Newman and Unger 2003, Rand 1995, Rand *et al.* 1995, Wells, Lee and Blaise 1998), but relatively few of them cover the marine field specifically, a recent exception being Blasco *et al.* (2016).

In our view, it is imperative that the field of marine ecotoxicology continue to broaden its perspective beyond the development of testing approaches, their application in regulating chemical and industrial discharges, EIA (environmental impact assessment), and general monitoring. This has occurred with considerable work on marine biomarkers (e.g., Depledge 1998; Ferard and Blaise 2013) from early work on MFOs (mixed function oxidases) to new studies involving the many advances in genomics and other omics (see section below). Importantly, the marine ecotoxicology field should start more visibly and formally to include concerns to human health from a variety of sources, e.g. chemicals, microbial pathogens, natural toxins, marine debris, and climate change through ocean acidification and warming.

There is a need to integrate these disciplines. A new framework (e.g. Fig. 6) and paradigm is needed for marine ecotoxicology, given its two major roles – protecting all components of ecosystems and protecting human health. How can this be done and should the focus only be on chemical contaminants?

Figure 4: Twenty-five years of oceans and human health (OHH).

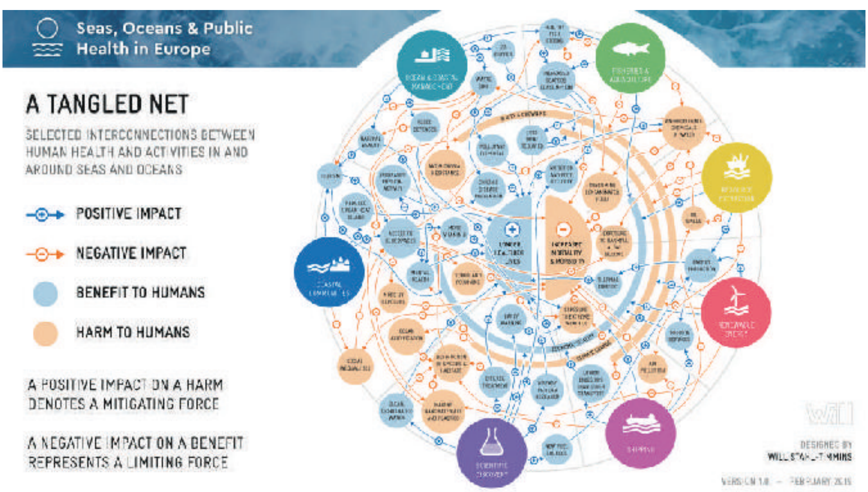

Figure 5: A tangled net of interactions between human health and ocean activites. Permission from Fleming *et al.* , 2019.

There is a need to understand the exposure regime imposed on organisms, including humans - the composition, concentrations over time and space, and the mode of toxic action of the specific agents , e.g., chemicals, especially the wide range of CECs, and “pharmaceuticals, PCPs, micro-plastics, nanomaterials, narcotics” (Stauber *et al.* 2016). Hence, the “lynchpin to action” (perhaps one of several) on the issues that may influence both ocean health and human health is having knowledge of all aspects of exposure (composition of the agent, the concentration, the length of exposure time, and biological indicators of exposure, i.e., biomarkers). What are organisms and humans being exposed to that is harmful and how can that be reduced or eliminated all together? From a MARTOX perspective, that means monitoring chemical levels in tissues of key organisms, for example, as we have been doing in the Gulf of Maine and Bay of Fundy via Gulfwatch (Chase *et al.* 2001, Elskus *et al.* 2020). This provides evidence about the risks to both marine organisms and people.

This important connection, especially if people are getting sick, gets the attention of politicians, bureaucrats and ocean managers, and hopefully problems are solved quickly, e.g., the classic example in eastern Canadian waters is the algal toxin outbreak in the 1980s that killed and sickened people (Todd 1993). Identifying and monitoring the distribution of the toxin was key to identifying the problem and resolving it. This happened very quickly, a well-documented case of fast government action when human health was at stake. Other examples include mercury poisoning of people living downstream of pulp mills, and the many health impacts to people who clean up coastal oil spills.

Understanding the exposure question is a core part of hazard and risk assessment – the 3 parts of ecological risk assessment (ERA) – exposure, uptake (bioaccumulation and biomagnification), and effects (toxicity). MARTOX is a major contributor to ERAs. The link between ERA and human health is unambiguous and important.

A second important linkage between ocean health and human health is the understanding of combined effects of stressors, how they interact as mixtures, on individuals and sub-individual levels of biological organization (tissues, cells, biological molecules, including genes) and considering cumulative effects – effects of multiple sub-lethal exposures over time and space. Studies with a range of marine organisms can give insights as to how at the sub-individual level of organization, chemicals may be having effects, on cellular and genetic processes.

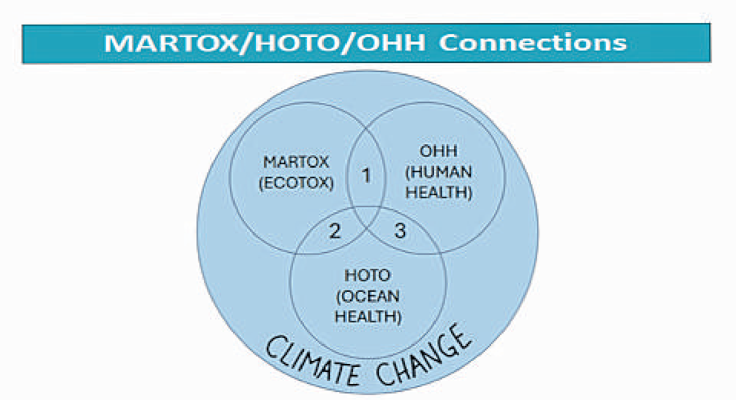

Figure 6: A new framework for marine ecotoxicology.

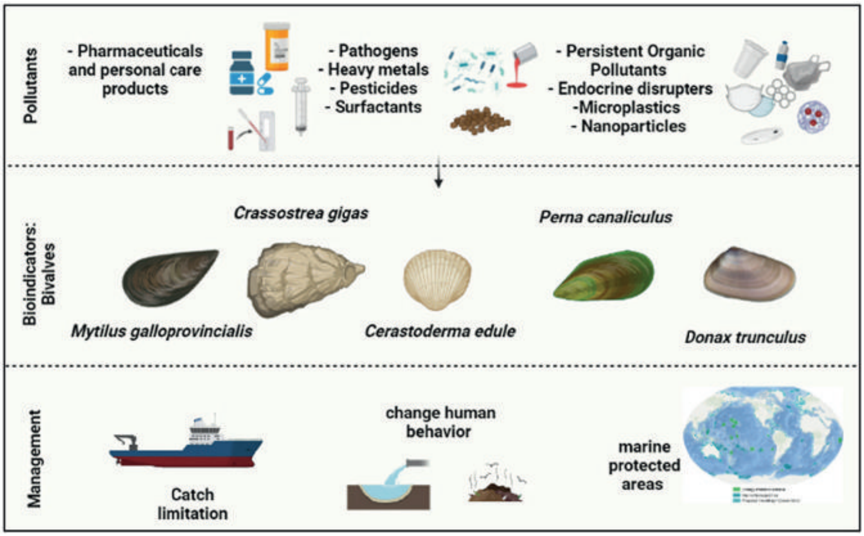

Figure 7: Bivalve Monitoring (Chahouri *et al.* 2023)

As well, all of the chemical and physical stressors are occurring against a backdrop of the many changes to the ocean caused by climate change, e.g. increased air and water temperatures, sea level rise, acidification, coastal erosion and increased sedimentation, etc. This is why understanding the effects of multiple stressors on marine organisms and people is critical – climate change and contaminants have potential interactions re the processes of toxicokinetics and toxicodynamics (Stauber *et al.* 2016).

In summary, understanding exposure and the effects of multiple stressors are two key parts of the science linking marine ecotoxicology with human health assessments, in an era of climate change (Fig. 6).

Linking marine ecotoxicology to ocean and human health

Over the past few decades (1970s to date), there has been a major evolution in MARTOX, one may even say a revolution in the science and its applications in pollution prevention and control. As mentioned above, approaches used experimentally in the laboratory, to those deployed in field conditions, have moved from acute, single species exposures to micro-and meso-cosms, full field exposure experiments, with considerable biomonitoring, and extensive field studies where toxic discharges and spills have occurred, e.g., major petroleum oil spills.

This progress was fueled by concerns about impacts from industrial and municipal effluents, specific persistent chemicals, and events such as oil spills in estuarine and coastal waters. This progress has been reported extensively over the past 50 years in the Proceedings of the ATW/CEW workshops/conferences, since 1980 at the SETAC Conferences (USA, Canada, other countries), and in the pages of its publication (Environmental Toxicology and Chemistry), along with many others.

Some of the latest developments in marine ecotoxicology include: the various omics methods and advances (Zhang *et al.* 2008); using AI in various methods (Rodrigues *et al.* 2021); developing the field of microbial ecotoxicology (Hellal *et al.* 2023); and developing new biomarkers for use in monitoring with bivalve molluscs such as Mytilus. (Chahouri *et al.* 2023) (Fig. 7). New fields of omics ecotoxicological research have evolved from advances in molecular biology and genetics – environmental genomics, eco-genomics, epigenetics, proteomics, metabolomics, and meta-barcoding. Important studies have linked ecological modeling with components of ecotoxicology (Park *et al.* 2008). Very likely, other advancements have been reported at recent CEW and SETAC Conferences.

The omic technologies are especially impressive and invaluable. “Consisting of genomics and ecogenomics, they have the power to reveal, in unprecedented detail, the cellular processes of an individual or biodiversity of a community, in response to environmental change, with high sample and observation throughput” (i.e., lots of samples) (Zhang *et al.* 2018). This allows a “direct linkage of ecological effects with the systems biology of organisms” (Zhang *et al.* 2018). As well, there are many applications of the methods in regulatory ecotoxicology (Zhang *et al.* 2018). eDNA meta-barcoding is now routinely used in the detection and quantification of effects of toxic substances on ecological communities, a huge technical advance in ecotoxicology (Zhang *et al.* 2018, Norgard *et al.* 2021). The same technologies are being applied in human toxicology (Goetz *et al.* 2011).

However, what is missing in marine ecotoxicology is the unequivocal connection of this new ecotoxicology science to the protection of human health, a connection that should be part of the framework (Fig. 6) and daily operation of all components of marine ecotoxicology. Unfortunately, this connection was missing in a recent but otherwise excellent overview of the field (Blasco *et al.* 2016).

There are examples where human health was considered in marine ecotoxicology studies, e.g., in Canada, the mercury discharges into rivers and estuaries in pulp mill effluents; concerns about the toxicity and link to medical issues (Reyes syndrome) from solvents in pesticide (fenitrothion) formulations; exposure of clean-up personnel to hydrocarbons at major oil spill sites; exposure of swimmers to microbial pathogens in sewage-contaminated waters (often still an issue in developed countries with treatment plants, e.g., the UK recently); and likely others.

As stated earlier, the public health – marine pollution connection gets attention and government action faster than if the concerns are simply about marine ecosystem health/ocean health. A current example is wide societal recognition of the plastics problem in the sea. It took several decades for this issue to surface, no pun intended! The concern now is about micro-plastics in seafood and the need to screen fisheries products for such contaminants (Santillo *et al.* 2017). The same concern has surfaced for PFAS (per- and poly -fluoroalkyl substances), chemicals that are pervasive in filter feeding molluscs in coastal waters, e.g. mussels and oysters, and hence demanding monitoring (and possibly depuration?) to ensure food safety (Health Canada 2025). More recently, there is major concern about climate change-ocean change (Kenny *et al.* 2020) and its implications for enhanced effects of pollutants in warming and more acidic waters.

Canada has been largely absent in focussing integrated attention on the topic of ocean and human health (Kenny *et al.* 2020, Watson-Wright 2022). This could change with the science of marine ecotoxicology helping to lead the way, especially if the federal government rebuilt its once active marine pollution and ecotoxicology programs.

Clearly, current marine ecotoxicology as a science (basic and applied) contributes critically to HOTO and OHH research, policy, and ocean management in numerous ways (updated from Depledge MS 2016):

- Identifying marine pollutant impacts on biota *in situ*, alerting responsible regulatory bodies to threats from specific chemicals that may contaminate seafood or other marine products, e.g. cultured seaweeds and bivalve molluscs.
- Supporting the use of marine indicators, i.e., biomarkers, in programs such as the long standing Global Ocean Observing System. This should continue and be strengthened with human health protection in mind.
- Addressing the problem of exposure to multiple contaminants (chemical mixtures) at the same time, following from Knap *et al.* (2002) and Sauve (2024) who stated that “we need to do a better job assessing combinations of chemical toxicants”. This is an area where microscale toxicity tests (Wells *et al.* 1998) can play an important role in key research.
- Linking marine environmental and human health risk assessments.
- Contributing to maps of coastal pollution, based on monitoring data that can be used with epidemiological data to track health threats to coastal people.
- Giving early warning of microbial pollution and associated human health threats from unsafe seafood, aerosolisation of algal toxins, PAHs such as from oils spills, and microbial pathogens that pose a respiratory threat to humans exposed to contaminated waters.
- Identifying newly emerging threats in marine ecosystems that may have

consequences for human health (e.g., Chemicals of emerging concern or CECs, pharmaceuticals, PFAS chemicals, endocrine disrupting chemicals).

- Linking extreme weather events (e.g. hurricanes) to increased coastal pollution (sewage, litter, plastics) and its impact on marine life and people. MARTOX must take into account the various impacts of climate change (Tlili and Mouneyrac 2021).

Marine scientists, ecotoxicologists and health practitioners, including toxicologists and epidemiologists, should collaborate to cement the connections between the disciplines and activate new research and pollution control initiatives. At the same time, marine ecotoxicologists can help to address some key questions while working directly with health professionals/practitioners, in the interests of protecting both ocean health and human health:

- Can MARTOX alert us to new human health threats?
- Which methods show the greatest promise?
- Can they provide data for health and economic impact assessments?
- How closely linked is coastal community health to coastal ecosystem health and the effects of pollution in Canada and other developed countries?
- On global scales, especially in less developed countries, to what extent do pollution incidents worsen the health and wellbeing of coastal peoples?

The Future

So often when we have considered what we need to do to achieve a better, more sustainable relationship between humans and the ocean, we have tended to focus on the problems we face currently and the measures we can take to improve matters. But over the next 10-15 years, the global environment (including the ocean environment) and human societies are likely to change at unprecedented rates. Global chemical production will increase several fold in the next decade or two, almost certainly resulting in more point source, but also more importantly, diffuse pollution of our seas. The increasingly diverse and complex chemical mixtures that are produced will be joined by a wider range of pathogens, especially in less developed areas of the World. The continuing quest to gather more marine resources, and to take advantage of the oceans energy potential is set to intensify, putting further pressure on marine ecosystems at a time when the physicochemical environment of the oceans is also being transformed by climate change. Acidification will modify the effects of chemical mixtures still further, added to which the progressive warming of the seas will affect uptake, biotransformation and excretion of pollutant chemical residues in ways that we do not fully understand.

Whether the long term migration of human populations to coastal regions will continue remains to be seen, but it seems likely. While the latest demographic information suggests that in the coming decades the global populations will eventually cease to grow and may enter a decline, it is still forecast that we will be joined by a further ca. 2 billion people by 2060, heaping further pressure on the oceans.

Marine ecotoxicologists in all sectors must play a critical role in the years to come in presenting, in compelling ways, the scientific evidence that pollution is not only robbing coastal communities (and those beyond) of the enormous wealth of benefits that we take for granted today, but also demonstrating that marine ecosystems and their biodiversity, which extend over 70% of the Earth's surface, is being progressively annihilated with huge implications for our future lives. Reversing such trends must be a priority.

Summary

The above discussion of ocean health shows that the science and practice of marine ecotoxicology, as it becomes increasingly sophisticated as an applied science, is linked to and is actively contributing to the protection of human health. This linkage should be strengthened with research and communication intertwined. The science has greatly benefited from 50 years of practice and sharing results at the ATW-CEW workshops, as well as at others. Well-funded, continued monitoring of marine water, sediments and selected species, supported by the latest omics techniques in the laboratory, can provide essential data to help protect human health in coastal communities.

This interdisciplinary approach, involving both the marine and health sciences, should draw the attention of ocean decision makers and managers at all levels. This hopefully will speed up the process of addressing the major marine pollution problems and solving them! Better still, by predicting and preventing problems through active interdisciplinary science, more effective management and care of the ocean will occur.

Acknowledgments

Our paper recognizes the many contributors, past and present, to marine ecotoxicology, and ocean and human health research, as well as the organizers of the special 50th anniversary session at the CEW in Kitchener-Waterloo, October,

2024. The paper is dedicated to the memory of Rachel Carson, on the 60th anniversary of her early passing in 1964. Her books about the sea were and still are a constant source of inspiration to many of us in the marine science field. May all of this effort inspire the next generation of ecotoxicologists in the quest for a cleaner and safer environment, on land, in freshwater, and at sea. We also thank our reviewers.

References

Anon./Bergami, E. (Ed.). 2021-22. Special Issue. Marine ecotoxicology and UN sustainability development goal 14: Towards sustainable solutions to reduce environmental hazards. Sustainability – special issue. www.mdpi.com/journal/sustainability/specialissues/marine_ecotoxicology

Blasco, J., Chapman, P.M., Campana, O., and Hampel, M. 2016. Marine Ecotoxicology. Current Knowledge and Future Issues. Elsevier, Academic Press, Amsterdam, Boston. 321 p.

Borja, A. *et al.* 2020. Moving towards an agenda on ocean health and human health in Europe. Front. Mar. Sci., Vol. 7, 2020. https://doi.org/10.3389/fmars.2020.00037

Bowen, R.E., Depledge, M.H., Carlarne, C.P. and Fleming, L.E. 2014. Oceans and Human Health. Implications for Society and Well-Being. Wiley Blackwell, Chichester, UK. 304 p.

Bundschuh, M. 2023. Ecological theory and concepts in ecotoxicology. Environ. Toxicol. Chem. 42(9): 1855-1856. June 14, 2023/Sept. 2023.

Byrne, M. 2012. Global change ecotoxicology. Mar. Environ. Res. 76: 3-15. May 2012.

Campbell, P.G., Hodson, P.V., Welbourn, P.M., and Wright, D.A. (Eds.) 2022. Ecotoxicology. Cambridge University Press, Cambridge, UK. 576 p.

Chahouri, A., *et al.* 2023. Bivalve molluscs as bioindicators of multiple stressors in the marine environment: recent advances. Cont. Shelf Res. 264, 15 July 2023, 105056.

Chase, M.E., S.H. Jones, P. Hennigar, J. Sowles, G.C.H. Harding, K. Freeman, P.G.Wells, C. Krahforst, K. Coombs, R. Crawford, J. Pederson and D. Taylor. 2001. Gulfwatch: Monitoring spatial and temporal patterns of trace metal and organic contaminants in the Gulf of Maine (1991-1997) with the blue mussel, *Mytilus edulis* L. Mar. Pollut. Bull. 42(6): 491-505.

Conlon, K. 2021. Marine debris and human health: an exposure pathway of persistent organic pollutants? Environ. Toxicol. Chem. 41(2): 263-265. (Feb. 2022).

De Almeida, E.A. 2023. CICTA 2021 conference: Advances in environmental toxicology in the face of emerging challenges from global contamination. Chemosphere 320, April 2023, 138051.

Demir, E. and Kacew, S. 2024. Editorial. Environmental toxicology and human health. Int. J. Mol. Sci. 25: 555. http://doi.org/10.3390/ijms25010555

Depledge, M.H. 1998. The ecotoxicological significance of genotoxicity in marine invertebrates. Mut. Res. 399(1): 109-122.

Depledge, M.H. MS2016. HSAC paper on key research questions in ecotoxicology. Unpubl. Man. Hazardous Substances Advisory Committee (HSAC), Department of Environment, Food and Rural Affairs, UK. 4 p.

Depledge, M.H. 2018. Oceans, health, and well-being. p. 199-204 in Werle, D. *et al.* The Future of Ocean Governance and Capacity Development. Brill, Nijhoff, Leiden, Boston.

Depledge, M.H. 2024. Re-thinking human interactions with the oceans. Royal Society Open Science, Oct. 2024. 11(10). DOI 10.1098 –rsos.240808.

Depledge, M.H., White, M.P. , Maycock, B. and Fleming, L.E. 2019. Time and tide. Our future health and wellbeing depend on the oceans. BMJ 2019.366:14761. DOI:10.1136/bmj.14671. July 17, 2019.

Di Giulio, R.T. and Hinton, D.E. 2008. The Toxicology of Fishes. CRC Press, Taylor and Francis Group, Boca Raton, FL. 1071 p.

Dixon, D.R. *et al.* 2002. Marine invertebrate eco-genotoxicology: a methodological overview. Mutagen.17(6): 495-507. Nov. 2002.

Duarte, B., Isabel, M., and Cacador, V. 2019. Ecotoxicology of Marine Organisms. CRC Press, Boca Raton, FL. 250 p.

Elskus, A.A., LeBlanc, L.A., Latimer, J.S., Page, D.S., Harding, G.C.H. and Wells, P.G. 2020. Monitoring chemical contaminants in the Gulf of Maine, using sediments and mussels (*Mytilus edulis*): An evaluation. Mar. Pollut. Bull. 153(Feb. 2020). 110956.

Ferard, J.-F. and Blaise, C. (Eds.). 2013. Encyclopedia of Aquatic Ecotoxicology. Springer, Dordrecht, Heidelberg, New York, London. Vols. 1 and 2. 1221 p.

Fleming, L.E., *et al.* (Eds). 2023. Oceans and Human Health. Opportunities and Impacts. 2nd Ed. Elsevier, and Academic Press. 832 p.

Fleming, L.E., Landrigan, P.J., Ashford, O.S., *et al.* 2024. Enhancing human health and wellbeing through sustainably and equitably unlocking a healthy ocean's potential. Annals of Global Health 90(1): 41, 1-28. DOI: https://doi.org/10.5334/aogh.4471

Fleming, L.E., Maycock, B., White, M.P. and Depledge, M.H. 2019. Perspective. Fostering human health through ocean sustainability in the 21st century. People and Nature 2019:1: 276-283. DOI:10.1002/pan3.10038

Goetz, A.K., Singh, B.P., Battalora, M., *et al.* 2011. Commentary. Current and future use of genomics data in toxicology: Opportunities and challenges for regulatory applications. Reg. Toxicol. Pharmacol. 61(2): 141-153.

Gregory, R.D., Bridle, J. and Wilson, J.D. 2024. What is the role of scientists in meeting the environmental challenges of the twenty-first century? Roy. Soc. Open Sci. 11: 240498. https://doi.org/10.1098/rsos.240498

Gu, J.-D. and Wang, Y.-S. 2015. Coastal and marine pollution and ecotoxicology. Ecotoxicology 24: 1407-1410. [a special issue of 40 papers]

Health Canada. 2025. State of Per- and Polyfluoroalkyl Substances (PFAS) Report. Environment and Climate Change Canada, and Health Canada. March 2025. Cat. No.: En84-395/2025E-PDF.

Hellal, J. *et al.* 2023. Unlocking secrets of microbial ecotoxicology: recent achievements and future challenges. FEMS Microbial Ecol. 99(10): 1-21. Oct. 2023. Fiad102.

Hester, R.E. and Harrison, R.M. 2011. Marine Pollution and Human Health. Issues in Environ. Sci. & Technol. Vol. 33. Roy. Soc. Chem., 2011. 168 p.

Hoffman, D.J., *et al.* (Eds.). 2003. Handbook of Ecotoxicology. 2nd Ed., Lewis Publishers, CRC, Boca Raton, London, New York, Washington, D.C. 1290 p.

Huzar, T. 2020. Is there a link between ocean health and damage to human health? Medical News Today, Dec. 12, 2020.

Jorgensen, S.E. Ed. 2010. Ecotoxicology. A Derivative of Encyclopedia of Ecology. Elsevier, Academic Press, Amsterdam, Boston. 390 p.

Kenny, T.-A., *et al.* 2020. Oceans and human health – navigating changes on Canada's coasts. Facets 5(1), Jan. 2020. 34 p. https://doi.org/10.1139/facets-2020-0035

Knap, A., Dewailly, E., Furgal, C., *et al.* 2002. Indicators of ocean health and human health: Developing a research and monitoring framework. Commentary. Environ. Health Perspectives 110(9): 839-845.

Landrigan, P.J. *et al.* 2020. Reviews. Human health and ocean pollution. Annals of Global Health. (also www.bc.edu/bcnews/landrigan-ocean-report)

Lear, L. 1997. Rachel Carson. The Life of the Author of Silent Spring. Henry Holt and Company ,New York. 634 p.

National Agricultural Library, US Department of Agriculture. 2022. New Approach Methodologies in Ecotoxicology Bibliography. 23 p. Last updated, May 2022.

National Research Council (NRC, USA). 1999. From Monsoons to Microbes: Understanding the Ocean's Role in Public Health. NRC, Wash., DC.

Newman, M.C. and Unger, M.A. 2003. Fundamentals of Ecotoxicology. 2nd Edition. Lewis Publishers, CRC, Boca Raton, London, New York, Washington, D.C. 458 p.

Nilsen, E. *et al.* 2019. Critical review: Grand challenges in assessing the adverse effects of contaminants of emerging concern in aquatic food webs. Environ. Toxicol. Chem. 38(1): 46-60.

Norgard, L., Olesen, C.R., Trojelsgaard, K., *et al.* 2021. eDNA metabarcoding for biodiversity assessment, generalist predators as sampling assistants. Scientific Reports 11, No. 6820 (2021).

Park, R.A., Clough, J.S. and Wellman, M.C. 2008. AQUATOX: Modeling environmental fate and ecological effects in aquatic ecosystems. Ecol. Modeling 213 (1): 1-15.

Parker, W.R., Pessah, E., Wells, P.G., and Westlake, G.F. 1977. Proceedings of the 3rd Aquatic Toxicity Workshop, held in Halifax, Nova Scotia, November 2-3, 1976. Tech. Rept., EPS-5-AR-77-1. 176 p.

Pinho, J.V. *et al.* 2022. The role of the ecotoxicology applied to seafood as a tool for human health risk assessments concerning PAHs. Int. J. Environ. Res. Public Health 19(3): 1211. Jan. 22/22.

Public Health Post. 2021. Human health and ocean pollution. https://publichealthpost.org/environment/humanhealth

Owen, R.A., Galloway, T.S., Hagger, J.A., Jones, M.B. and Depledge, M.H. 2008. Biomarkers and environmental risk assessment: Guiding principles from the human health field. Mar. Pollut. Bull. 56(4): 613-619. (April 2008).

Owen, R.A., Depledge, M.H., De Lurio, J., Bardsley, S., and Palomino, M.A. 2014. Ch. 10. Emerging issues in oceans and human health: Managing uncertainty and new knowledge. p. 267-289 in Bowen *et al.* 2014.

Rand, G.M. (Ed.) 1995. Fundamentals of Aquatic Toxicology. Taylor and Francis, Boca Raton, FL. 1125 p.

Rand, G.M., Wells, P.G., and McCarty, L.S. 1995. Introduction to aquatic toxicology. In Rand, G.M. Ed. Fundamentals of Aquatic Toxicology. Taylor and Francis, Boca Raton, FL. p. 3-67.

Rashid, U., Armitage, D., Bailey, M., and Cheung, W.W.L. 2024. Sea Change. Charting a Sustainable Future for Oceans in Canada. UBC Press, Vancouver, BC. 256 p.

Reamer, M.B. 2022. Communicating ocean and human health connections: An agenda for research and practice. Front. Public Health, Section on Planetary Health, 10-2022. https://doi.org/10.3389/fpubh.2022.1033905

Reichelt-Brushett, A. (Ed.). 2023. Marine Pollution – Monitoring, Management and Mitigation. Springer Nature. (open access). www. link.springer.com

Rodrigues, N.M. *et al.* 2021. Artificial intelligence meets marine ecotoxicology. Biology (Basel), 2021, Sep:10(9): 932.

Rodriguez-Romero, A., *et al.* 2021. Acquiring an evolutionary perspective in marine ecotoxicology to tackle emerging concerns in a rapidly changing ocean. Sci. Total Environ. 2021. April 10:764:142816.

Sanderson, H. and Solomon, K. 2009. Contaminants of emerging concern challenge ecotoxicology. Environ. Toxicol. Chem. 28(7): 1359-1360.

Santillo, D., Miller, K. and Johnston, P. 2017. Invited Commentary. Microplastics as contaminants in commercially important seafood species. Intergr. Environ. Assess. Manag. 25 April 2017. http://doi.org/10.1002/ieam.1909

Sauve, S. 2024. Toxicology, environmental chemistry, ecotoxicology, and One Health: definitions and paths for future research. Front. Environ. Sci. 18 March. 2024. Sec. Toxicol., Pollution and Environment, Vol. 12, 2024.

Schiedek, D. *et al.* 2007. Interactions between climate change and contaminants. Mar. Pollut. Bull. 54: 1845-1856.

Short, R.E., *et al.* 2021. Review of the evidence for oceans and human health relationships in Europe: A systematic map. Environ. Interntl. 146, Jan. 2021, 106275.

Shyu, D.J.H. *et al.* 2024. Special issue. Marine ecotoxicology and risk assessment of emerging environmental pollutants. J. Hazardous Materials Advances, 20th Sept., 2024.

Siddiqui, S., and Brander, S.M. 2024. Aquatic Ecotoxicology. Springer. (see p. 131-138 – aquatic ecotoxicology and human health)

Stauber, J.L., Chariton, A., and Apte, S. 2016. Chapter 10. Global change. In Blasco *et al.*, p. 273-313.

Sumaila, U.R. *et al.* 2024. Sea Change. Charting a Sustainable Future for Oceans in Canada. UBC Press, Vancouver. 256 p.

Taylor, L.N., Doe, K.G., Scroggins, R.P. & Wells, P.G. 2013. Regulatory ecotoxicology testing in Canada – activities and influence of the Inter-Governmental Ecotoxicological Testing Group. Water Qual. Res. Jour. Canada 48(1): 14-29.

Taylor, L.N. and Scroggins, R.P. 2013. Biological test methods in ecotoxicology. p. 197-204 in Ferard and Blaise.

Tlili, S. and Mouneyrac, C. 2021. New challenges of marine ecotoxicology in a global change context. Mar. Pollut. Bull. 2021, May: 166: 112242.

Todd, E.C.D. 1993. Domoic acid and amnesic shellfish poisoning – a review. J. Food Protection 56(1): 69-83.

University of Exeter. Nd. Translating science into real world impact. Video. www.exeter.ac.uk/research/healthieroceans/ecotox/

Watson-Wright, W. 2022. The ocean and human health as a meta-discipline: Opportunity for Atlantic Canada. Proc. NS Inst. Sci. 52(2): 181-195.

Watson-Wright, W., Wells, P.G., Duce, R.A., *et al.* 2024. The UN Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) – An ocean science-policy interface standing the test of time. Mar. Pollut. Bull. 199 (2024). 115917

Wells, P.G. 2000. Marine Ecotoxicology: Lecture notes, readings, bibliographies and laboratory methods. Unpubl. Report, Bermuda Biological Station for Research, Inc., St. George, Bermuda. June-July 2000.

Wells, P.G. 2009. Chapter 84. Aquatic Toxicology: Concepts, {Practice, New Directions. p. 2123-2155 in General and Applied Toxicology. Vol. 4. Third Edition. Eds - B. Ballantyne. T.C. Marrs, T. Syversen. John Wiley and Sons Ltd., UK.

Wells, P.G. 2013. Observing the entocommensal ciliate fauna of sea urchins, Strongylocentrotus spp. – an exercise that illustrates the wonders of symbiosis. Symbiosis 60(1): 45-47.

Wells, P. G. 2016. A career-based perspective of science-policy linkages in

Environment Canada: The role of information in managing human activities in our ocean spaces. In B. H. MacDonald, S. S. Soomai, E. M. De Santo, & P. G. Wells (Eds.), Science, Information, and Policy Interface for Effective Coastal and Ocean Management (pp. 367-388). Boca Raton, Florida: CRC Press, Taylor & Francis Group.

Wells, P.G. 2018. Health of the Ocean. p. 192-198 in Werle, D. *et al.* The Future of Ocean Governance and Capacity Development. Brill, Nijhoff, Leiden, Boston.

Wells, P.G. 2021. Considering lag times in environmental science and management – An essay to engage environmental biologists. Can. Soc. Environ. Biol., Bull. 78(3), Fall, 2021. 8 p.

Wells, P.G. 2022. Reflections from a career in marine environmental science and management. In Proc. 47th Can. Ecotox. Workshop, Halifax, NS. 8 p.

Wells, P.G. 2023. Editorial. Living in a global environmental emergency ward – the need to address problems with science, action and speed. Proc. NS Inst. Sci. 53(1): 1-4.

Wells, P.G. and Addison, R.F. (Eds.) 1985. Proceedings of the Tenth Annual Aquatic Toxicity Workshop, November 7-10, 1983, Halifax, Nova Scotia. Can. Tech. Rept. Fish. Aquat. Sci. No. 1368. Dept. Fish. and Oceans, Ottawa, ON. 475p.

Wells, P.G. and Doe, K.G. 2014. Applied aquatic toxicology: Protecting the waters of Atlantic Canada.. In Voyage of Discovery, Nettleship, D. *et al.*, (Eds.), BIO-Oceans Assoc., Dartmouth, NS. Pp. 315-321.

Wells, P.G., Lee, K., and Blaise, C. (Eds.) 1998. Microscale Testing in Aquatic Toxicology. Advances, Techniques, and Practice. CRC Press, Boca Raton, Boston, London. 679 p.

Wells, P.G. and Rolston, S.J. (Eds.). 1991. Health of Our Oceans. A Status Report on Canadian Marine Environmental Quality. Environment Canada, Ottawa and Dartmouth. 186 p.

Windom, H. 1991. GESAMP: two decades of accomplishment. International Maritime Organization, London, UK. 40 p.

World Resources Institute. (Authors: Ashford, O., and Wood, K.). 2024. 4 ways ocean health is critical to human health everywhere. April 11, 2024.

Zhang, X., *et al.* 2018. Omics advances in ecotoxicology. Environ. Sci. Technol. 52: 3842-3851.

APPENDIX 1

Year	Chairs	Organizing Committee
1974 Winnipeg	John Loch & John Davis	None identified
1975 Toronto	Gordon Craig	C. Inniss, D. Wells, M. Whittle, K. Suns, J. Reinke, T. Lagan, W. Baksi, P. Hunter, J. Fitzsimons, S. Norman
1976 Halifax	Ed Pessah & Peter Wells	R. Parker, G. Westlake
1977 Vancouver	John Davis	G. Greer, I. Birtwell, G. Vigers, R. Hoos, M. Waldichuk, B. Smythe, N. Holeman, I. Shand, P. Vroom, S. Nelles, D. McLeay
1978 Hamilton	Peter Hodson	P. Wong, A. Niimi, V. Cairns, U. Borgman, K. Kaiser B. Blunt, O. Kramar, C. Loveridge, L. Luxon, D. Spry
1979 Winnipeg	Jack Klaverkamp & Lyle Lockhard	A. Blouw, R. Clarke, S. Leonhard, D. Malley, M. McLean, E. Scherer, M. Yakimischak
1980 Montreal	Norman Birminham & Gerard Leduc	C. Blaise, M. Speyer, P. Couture, G. Joubert, B. Hummel, R. Van Coillie, C. Thellen, M. Lebel, L. Sprags
1981 Guelph	Gordon Craig & Keith Solomon	F. Beamish, K. Day, J. Hilton, P. Hodson, D. Holdway, N. Hutchinson, N. Kaushik, D. Rogers, J. Sprague, C. Wren
1982 Edmonton	Bill Lake	A. Hrynyk, A. Beckett, W. Mackay, M. Strosher, B. Munson, B. Hammond, J. Kotler, J. Retallack
1983 Halifax	Richard Addison & Peter Wells	M. Hutcheson, R. Parker, J. Uthe, G. Westlake
1984 Vancouver	Glen Geen	I. Birtwell, K. Hall, A. McCarter, D. McLeay, R. Morley M. Roch, R. Watts
1985 Thunder Bay	George Ozburn & Howard McComick	A. Smith, MOE staff, Lakehead U. staff.
1986 Moncton	J. Lakshminarayana	T. Pollock, R. Cote, M. Gilbertson, H. McCormick, J. Uthe, P. Wells, V. Zitko, P. LeBlanc, C. Morry, R. Parker, M. Butler, T. Clair, D. Eidt, P. Pearce, D. Besner, P. Maltais, Y. Poussart, R. South, R. Addison.
1987 Toronto	Gary Westlake	S. Abernethy, A. Niimi, K. Solomon, P. Stokes,
1988 Montreal	Raymond Van Coillie	A. Champoux, P. Anderson, J. Boulva, J. Brodeur, R. Brouzes, J. Cerf, G. Chevalier, R. McLean, P. Ross, H. St-Martin, C. Blaise, D. Brouard, R. Coté, P. Courure. J. de la Noüe, P. Lundahl, C. Marengo, J. Massicotte – Pellerin, B. Pinel-Alloul, Y. Roy, H. Sloterdijk, M. Speyer, C. Thellen, B. Trotier, Y. Vigneault, N. Birmingham, M. Sinotte.

APPENDIX 1

1989		Canceled
1990 Vancouver	Peter Chapman	K. Hall, L. Harding, D. McLeay, M. Nassichuk, S. Yee, W. Knapp, E. Power, W. Schwartz, L. Reid.
1991 Ottawa	Margaret Taylor	L. Bendell-Young, J. Jensen, K. Lloyd, C. Macdonald, F. Pick, R. Pierce, R. Scroggins, R. Shearer, C. Wyndham
1992 Edmonton	Earl Baddaloo	A. Kozlowski, W. Mackay, M. Mackinnon, J. Moore, S. Ramamorthy, P. Humphrey
1993 Quebec City	Raymond Van Coillie	C. Thellen, P. Campbell, H. Pagé, L. Hare, L. Martel, J. Piuze, R. Schetangne, R. Siron, B. Pinel-Alloul, P. Anderson, D. Brouard, J. Labrie, N. Birmingham, Y. Roy, Y. Bois, P. Lundhal, P. Riebel
1994 Sarnia	Scott Munro & Ted Kierstead	K. Solomon, G. Craig, G. Westlake, M. Lines, A. Niimi, S. Thornley, J. Parrott, C. Facca, K. Hall.
1995 St. Andrews	Kats Haya	J. Arsenault, L. Buridge, S. Courtenay, W. Fairchild, B. Waiwood, L. White, V. Zitko, H. Akagi, B. Best, M. Bender, B. Hatt, M. Saunders, M. Lyons, K. MacKeigan B. Neilson.
1996 Calgary	Stella Swanson & D. Treissman	M. Brown, L. Clader, R. Compton, C. Gervais, S. Goudey, L. Linton, J. Nagendran, T. Nason, T. Nerberg, R. Robinson, S. Silva, B. Steinback.
1997 Niagara Falls	Joanne Parrott & Gordon Craig	P. Dehn, G. Dixon, D. Hart, S. Humphrey, K. Holtze, P. McKee, T. Moran, A. Niimi, L. Novak, D. Rokosh, C. Wren, M. Burley, L. Gysbers, J. Smits.
1998 Quebec City	Raymond Van Coillie	C. Thallen, G. Van Coillie, H. Pagé, C. Blaise, J. Bureau, R. Chassé, C. Couillard, I. Guay, L. Hare, C. Langios, L. Martel, L. Parent, S. Pauwels, R. Prairie, R. Schetagne, G. Sunahara, P. Wells, J. Pellerin, J. Karau, J. Labrie, Y. Bois, C. Côté, I. Cloutier, G. Grenon, G. Craig, L. Trudel, L. Veilleux.
1999 Edmonton	Earl Baddaloo	D. Birkholz, M. Brown, M. Clendenan, S. Goudey, M. Mah-Paulson, A. Verbeek, M. Fairbaim,
2000 St. Jonh's	Kathy Penny & Kim Coady	M. Murdock, R. Parker, D. Snow, P. Jackman, E. Tracy, S. Whiteway, P. Orr, E. Luiker.
2001 Winnipeg	Michael McKernan Brian Wilkes	B. Bayer, G. Craig, D. Harron, K. Mathers, M-A. Phare, G. Stern, D. Williamson
2002 Whistler	Curtis Eickhoff & Graham van Aggelen	J. Boyd, D. Bright, J. Bruno, K. Hall, P. Keen, C. Kennedy, K. Kinnee, P. Lim, C. Lowe, A. Niimi, M. Paine, B. Raymond, S. Yee.

APPENDIX 1

2003 Ottawa	Kathleen Hedley	M. Bombardier, S. Desjardins, G. Gilron, V. Hodge, G. Kaminski, B. Kilgour, J. McGeer, T. Moon, J. Nadeau, C. Portt, G. Rawn, S. Roe, M. Schwartz, D. Spry, G. Tetreault, V. Trudeau, S. Winch.
2004 Charlottetown	Les Burridge	W. Ernst, W. Fairchild, K. Haya, J. Hellou, R. Allen-Jarvis, B. Kilgor, K. Lee, M. Murdock, R. Parker, S. Smith-Gray, S. Steller, K. Teather.
2005 Waterloo	George Dixon & Scott Munro	G. Craig, P. Dehn, A. Farwell, J. Green, L. Lee, M. McMaster, T. Moran, W. Norwood, C. Portt, J. Schroeder, J. Sherry, G. Stephenson, G. Tetreault.
2006 Jasper	Barry Munson	N. Ali, J. Ferone, J. Froese, P. Siwik, M. Dube, V. St.Loui, L. Noton, C. Renzenbrink, M. Foster, L. Wood, D. Beauparlant, S. Boss, T. Steiglitz, C. Maxwell, A. Petersen, C. Rickwood, A. Squires, R. Beaulieu, M. Gray, K. Fraser.
2007 Halifax	Karen Kidd & Rosalie Allen Jarvis	K. Doe, K. Haya, G. Benoy, C. Burnett, S. Courtenay, C. Hedley, J. Hellou, T. Jardine, C. Moore, R. Mroz, K. Munkittrick, M. Murdock, L. Rutherford, V. Soehl, M. van den Heuvel, P. Wells.
2008 Saskatoon	Karsten Liber	A. Brown, C. Burnett, M. Dubé, D. Duro, J. Geisy, S. Geisy, N. Glozier, K. Hancock, M. Hecker, K. Himbeault, D. Janz, P. Jones, P. Krone, S. Niyogi, M. Pietrock, J. Price, S. Sedgewick, A. Squire, L. Weber.
2009 La Malbaie	Louis Martel & Michel Fournier	P. Benoit, D. Berryman, T. Bosker, M. Bouchard, O. Bouchet, A. Boullimant, P. Campbell, L. Champoux, C. Couillard, N. Dassylva, F. Gagné, C. Gagnon, I. Guay, P. Juneau, E. Lacroix, M. Lebeuf, L. Parent, R. Patenaude, J. Pellerin, B. Vigneault, P.Y. Robidoux, G. Tiffault-Bouchet.
2010 Toronto	Tim Fletcher & Douglas Holdway	T. Watson-Leung, P. Welsh, N. Feisthauer, D. McLatchy, G. van der Kraak, A. Bartlett, W. Norwood, C. Metcalfe, M. Dutton, B. Kilgour, L. Novak, M. Rendas, D. Poirier, J. Anderson, Y. Gopalapillai, L. McCarthy, J. Schroeder, M. Nowierski, D. Simmons, J. Guchardi
2011 Winnipeg	Karen Mathers & David Heubert	J. Anderson, B. Glowacka, M. Hanson, J. Heibert, H. Loomer, M. McKernan, S. Veroukis, C. Wong.
2012 Sun Peaks	Joanne Harkness & Graham van Aggelen	J. Bruno, C. Eickhoff, C. Helbing, C. Kennedy, P. Kickham, H. Loomer, C. Lowe, J. Muscatello, R. Prosser, H. Schroeder, B. Yates.
2013 Moncton	Paula Jackman & Les Burridge	M. Murdock, R. Estabrooks, D. Daoud, S. E. Maher, J. Van Geest, R. Prosser, J. Challis, G. Schroeder, L. Miller

APPENDIX 1

2014 Ottawa	Lisa Taylor & Carrie Rickwood	S. Agius, B.Cameron, J.Challis, M. Desforges, C. Eickhoff , G. Gilron, Y. Gopalapillai, S. MacLeod, A. Muhametsafina, L, Novak, M. Rendas, G. Schroeder, P. Siwik, L. Tupper-Ring, L. Van der Vliet
2015 Saskatoon	Karsten Liber & David Janz	J. Anderson, A. Brown, L. Doig, M. Hanson, M. Hecker, N. Hogan. T. Jardine, P. Jones, T. Klein, J. Leung, C. Morrissey, A. MuhamSom Niyogi, F. Price, K. Raes , E. Robertson, L. Weber, K. Wells, S. Wiseman, M. Wickstrom
2016 Edmonton	Kathleen Racher, Paula Siwik, Anne Wilson	I. Carleton-Dodds, L. Cymbalisty, C. Evans, A. Gainer, E. Gillio Meina, G. Gilron, G. Goss, D. Green, R. Krohn, J. Leung, J. Little, K. Munter, L. Phalen, D. Philibert, G. Schroeder, R. Sharpe, K. Tierney, R. Walbourne
2017 Guelph	Paul Sibley & Ryan Prosser	J. Anderson, T. Darwish, É. Gilroy, N. Feisthauer, J. Kirk, E. Gillio Meina, Y. Gopalapillai, D. Green, M. Hanson, J. Leung, R. Nesbitt, L. Ramilo, J. L. Rodriguez Gil, D. Simmons, H. Sonnenberg, G. Stephenson, G. Tétreault, L. Van der Vliet
2018 Vancouver	Curtis Eickhoff , Bonnie Lo, Vicki Marlatt	N. Baldwin, A. de Bruyn, A. Buckman, S. Calbick, G. Craig, B. Danis, M. DiMauro, L. Du Gas, J. Elphick, M. Eng, E. Franz, A. Gainer, G. Gilron, D. Green, C. Grimard, P. Howes, D. Huebert, S. Love, R. Loveridge
2019 Québec	Caroline Côté , Patrice Couture, Lise Parent	R. Allen Jarvis, R. Bérubé, T. Black, M. Boily, M. Desrosiers, J.-P. Gagné, C. Gagnon, I. Guay, S. Graves, H. Ikert, V. Langlois, M. Martyniuk, H. Medhi, E. Millar
2020		Deferred due to COVID pandemic
2021 Halifax	Rita Mroz, Laura Tupper-Ring , Abby van der Jagt	K. Oakes, T. Small, E. Smith, B. de Jourdan, J. Berry, M. Murdoch, C. Moore, S. Wallace, C. Tavakoli
2022 Winnipeg	Julie Anderson, Mark Hanson, José Luis Rodriguez-Gil	H. Jovanovic, J.-P. Desforges, J. Muscatello, K. Wells, L. King, A. Collins, L. Loseto, H. Jovanovic, J. Challis, C. Lobson, C. Tavakoli, B. Humeniuk, T. Black, C. Brown, F. Taridashti, G. Pazmino Sosa, K. Robichaud, L. Corrie, R. Koumrouyan, K. Carriere, S. Wallace, J. Hiebert
2023 Ottawa	Leana Van Der Vliet, Rebecca Dalton, Stacey Robinson,	R. Lavoie, A. Bartlett, T. Black, V. Sesin, G. Gilron, C. Tavakoli, E. Gilroy, B. Kilgour, B. Humeniuk, R. Smith, S. Marteinson
2024 Kitchener - Waterloo	Sarah Crawford, Paul Craig, Beverley Hale, Jim McGeer	L. Novak, G. Gilron, K. Robichaud, J. Velichka, G. Tetreault, E. Leoard, E. Gilroy, C. Martinko, R. Prosser, T. Black, Y. Gopalapillai, R. Smith, C. Stewart.

APPENDIX 1

2025 Victoria	Jennie Christensen, Caren Helbing, Guy Gilron, James Elphick	K. Mill, E. Field, T. Black, E. Irving, G. LaBine J. Emery, G. Labine, L. Bowron, B. Lo, C. Stewart, D. Calik

PLAYLE AWARD WINNERS		
	M.Sc.	B.Sc.
2025	Katherine Anderson-Bain *University of Lethbridge*	Ivana Gulati *University of Saskatchewan*
2024	Mattew Schultz *University of Saskatchewan*	Kailey Carriere *University of Manitoba*
2023	Chloe Devoy *University of Lethbridge*	Chantel De Lange *University of Saskatchewan*
2022	Rebecca Eldridge *University of Manitoba and Huntsman Marine Science Centre*	Yamin Raza *University of Lethbridge*
2021	Not awarded	Not awarded
2020	Meeting Deferred - COVID	
2019	Not awarded	Not awarded
2018	Connor Pettem *University of Saskatchewan.*	Ulyana Fuchylo *University of Saskatchewan*
2017	Julie Bilodeau *U of Ottawa* Stephanie Schiffer *University of Saskatchewan*	Not awarded
2016	Anita Massé, University of Saskatchewan.	Not awarded
2015	Laura Phalen *University of Prince Edward Island*	Not awarded
2014	Shari Sahmer *University of Waterloo*	J. Andrew Alexander *University of the Fraser Valley*
2013	Amanda Carew *University of Victoria*	Emily-Jane Costa *Wilfrid Laurier University*

PLAYLE AWARD WINNERS		
	M.Sc.	**B.Sc.**
2012	Eric Franz *University of Saskatchewan*	Danielle Louise Gordon *University of PEI*
2011	Meghan Goertzen *University of Saskatchewan*	Laura Jane Phalen *University of PEI*
2010	Carolyn Brown *University of Waterloo*	Sean Anthony McNeill *University of PEI*
2009	Virginie Roy *Université de Montréal*	not awarded
2008	Jocelyn Kelly *University of Saskatchewan*	Mary Rose Bufalino *Wilfrid Laurier University*
2007	Adrienne Fowlie *Queen's University*	Henrietta Parnas *University of Ottawa*
2005	Playle Award created	

Canadian Ecotoxicity Workshop (CEW): Fifty Years 1974 – 2024

Gordon R. Craig presented at the first ATW in 1974 and hosted the second meeting the following year. He was a long time Board member, appointed and elected, for many of the years of the organization. While on the Board he created the first web site, administration program, financial sustainability model and contributed to the re-stating of the corporation by-laws for CEW. His career spanned working with the Ontario Ministry of Environment, BEAK Consultants and he started his own firm G.R.Craig & Associates. He retired in 2015 and lives in Nanoose Bay, BC.
gordon@grcraig.com

Rick Scroggins began his career with BEAK Consultants and then joined Environment Canada in the mid-1980s where he created the standardized biological test method program. He also was the driving force behind the creation of a world-class soil effects research laboratory group which is unique in Canada. During his years with BEAK and EC, Rick has always been a strong supporter of ATW/CEW, participating in 37 of the 50 workshops. As a volunteer to the CEW Board of Directors, he served as chair of the CEW Advisory Committee for 5 years.
Rick retired in 2024 and lives in Ottawa. ON.
rick.scroggins2@gmail.com

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