Journal of Great Lakes Research xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

Biological and chemical contaminants as drivers of change in the Great Lakes–St. Lawrence river basin ☆

Emily R. Cornwell [a,*,1], Jean-Olivier Goyette [b,1,2], Ryan J. Sorichetti [c,1,3], David J. Allan [d,4], Donna R. Kashian [e,5], Paul K. Sibley [f,6], William D. Taylor [g,7], Charles G. Trick [c,3]

[a] Department of Microbiology and Immunology, Cornell University College of Veterinary Medicine, Ithaca, NY 14853, USA
[b] Groupe de recherche interuniversitaire en limnologie et en environnement aquatique (GRIL), Département de Sciences Biologiques, Université de Montréal, Montréal, Québec H3C 3J7, Canada
[c] Department of Biology, Western University, London, Ontario N6A 3K7, Canada
[d] School of Natural Resources and Environment, University of Michigan, Ann Arbor, MI 48109, USA
[e] Department of Biological Sciences, Wayne State University, Detroit, MI, USA
[f] School of Environmental Sciences, University of Guelph, Guelph, Ontario N1G 2M7, Canada
[g] Department of Biology, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada

ARTICLE INFO

Article history:
Received 7 November 2013
Accepted 22 June 2014
Available online xxxx

Communicated by: Irena Creed

Keywords:
Toxic substances
Contaminant
Organic compounds
Eutrophication
Pathogen

ABSTRACT

Many initiatives since the early 1900s have been implemented to maintain water quality within the Great Lakes–St. Lawrence River basin. Despite these substantial efforts, emerging and re-emerging biological and chemical contaminants continue to pose serious human, animal, and ecosystem health risks. With over 100 biological and chemical contaminants detected in the basin and over 600 persistent and bio-accumulative contaminants listed in international databases, the threat of these contaminants to the basin is immense. This article discusses examples of legacy and emerging contaminants and their interactions with other drivers within the basin. A historical review of these contaminants from the past 50 years (1963 to present) has been prepared, as well as a synthesis of their current state. From this information and based on local and global initiatives and reports, three future scenarios for contaminants have been described projecting to the next 50 years (present to 2063), which are categorized as Status Quo, Utopian, and Dystopian. These are meant to categorize the possible range of occurrences and help decision makers prepare for various management options and improve resilience to future changes. In addition, we have highlighted some tools that are needed to effectively detect emerging contaminants in the basin. By exploring the plausible future scenarios of contaminants in the basin, we aim to highlight the need for bi-national agreements and initiatives to be developed and extended, both in time and scope, to restore and protect the basin and encourage ecosystem health.

Introduction

The Great Lakes basin contains one-fifth of the world's surface freshwater and is an important economic driver in the US and Canada. If the Great Lakes basin stood alone as an independent country, it would have the world's fourth largest economy (WBC, 2013). Biological contaminants (microorganisms or microbial byproducts that are pathogenic to humans and/or other animals) and chemical contaminants (synthetic chemical compounds or chemicals naturally found at relatively low concentrations) have entered the basin throughout modern history and have significantly altered its state (Fig. 1). Contaminants can adversely affect ecosystem health, human health or commerce. Furthermore, multiple stressors threaten the Great Lakes basin and many of the ecosystem services they provide. Physical, biological, and chemical processes interact within a context of uncertainty exacerbated by other drivers of change operating within the basin. These non-linear dynamics are mainly driven by self-organization, feedback, and threshold mechanisms, making the basin a complex socio-ecological system (Ostrom, 2009). Knowledge of the historical trends of contaminants and interactions with the environment is necessary to understand the current state of the Great Lakes basin and best inform future management decisions.

☆ The Great Lakes Futures Project brought together graduate students and expert mentors from universities and institutions in Canada and the United States.

* Corresponding author. Tel.: +1 607 253 4028.
E-mail addresses: erc58@cornell.edu (E.R. Cornwell), jean-olivier.goyette@umontreal.ca (J.-O. Goyette), rsorich@uwo.ca (R.J. Sorichetti), dallan@umich.edu (D.J. Allan), donna.kashian@wayne.edu (D.R. Kashian), psibley@uoguelph.ca (P.K. Sibley), wdtaylor@uwaterloo.ca (W.D. Taylor), cyano@uwo.ca (C.G. Trick).

[1] These authors contributed equally and are listed in alphabetical order.
[2] Tel.: +1 514 343 0912.
[3] Tel.: +1 519 661 3899; fax: +1 519 661 3935.
[4] Tel.: +1 734 764 6553; fax: +1 734 904 5697.
[5] Tel.: +1 313 577 8052; fax: +1 313 741 2055.
[6] Tel.: +1 519 824 4120; fax: +1 519 837 0442.
[7] Tel.: +1 519 888 4567x2556; fax: +1 519 746 0614.

http://dx.doi.org/10.1016/j.jglr.2014.11.003
0380-1330/

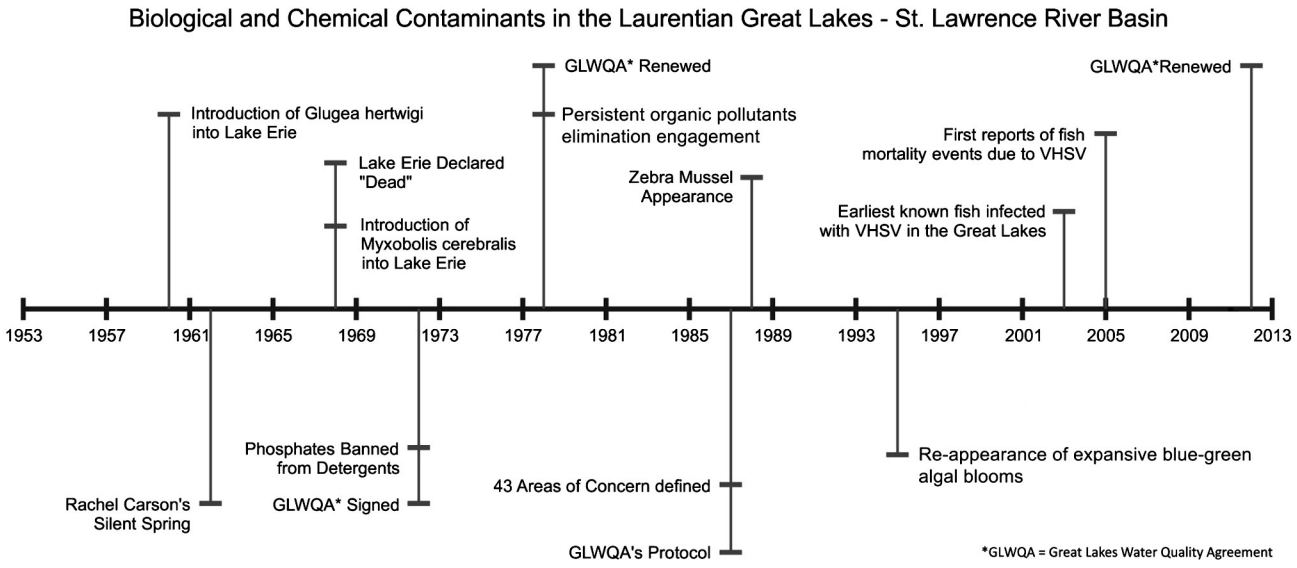

Fig. 1. Timeline over the past 50 years depicting significant events related to biological and chemical contaminants in the Great Lakes basin.

Legacy contaminants in the Great Lakes basin, which have been monitored since the 1960s and are regulated or banned but that are still of concern, have been thoroughly reviewed elsewhere (Baumann and Whittle, 1988; DeVault et al., 1996; Hebert et al., 1994; Hickey et al., 2006; Loganathan and Kannan, 1994). This article presents the trends of a subset of key biological and chemical contaminants affecting the Great Lakes basin since 1963 as well as discusses their effects on human and animal health. It then focuses on examples of their individual and combined interactions and places this in the context of a socio-ecological system by considering interactions with other drivers of change, including water quantity, governance and geopolitics, economy, demographics & societal values, climate change, and aquatic invasive species. This article concludes with three plausible scenarios and evidence-based hypotheses about future trends of the contaminants that we postulate should be of mutual concern between US and Canada, projecting to 2063 (50 years in the future), as well as recommendations regarding the role of biological and chemical contaminants in shaping the future of the Great Lakes basin.

Historical legacies from contaminants in the Great Lakes

Technological advancement

During and immediately following World War II, the idea of a 'better life through chemistry' became prominent according to a touchstone slogan of the chemical company DuPont. These years corresponded to the development of large-scale farming practices for which many agricultural pesticides were patented. Rachel Carson's *Silent Spring* (Carson, 1962) alerted the public to unintended consequences of pesticides. Restrictions were then placed on many chemical pollutants in the 1970s and 1980s through the Great Lakes Water Quality Agreement (GLWQA), and protocols were signed and subsequently renewed from 1972 to 2012 "to restore and maintain the chemical, physical and biological integrity of the Great Lakes" (GLWQA, 2012).

Despite these efforts, today's Great Lakes basin food webs are exposed to multiple chemical contaminants (Klaper and Welch, 2011). There are 22,263 commercial chemicals in Canadian and US databases that are likely infiltrating North American and Arctic ecosystems. Of these, 610 are considered persistent and bio-accumulative chemicals, 101 have been detected in environmental samples and 47 are on routine monitoring lists (Howard and Muir, 2010). The principal reason so few of these chemicals are routinely monitored is the challenge of developing sensitive analytic methods and appropriate detection limits. Besides legacy contaminants, another group gaining recognition is the contaminants of emerging concern, for which no guidelines or criteria exist and risks often are not yet known or poorly understood. The latter include some current-use pesticides, flame retardants, personal care products, and pharmaceuticals, as well as biological contaminants such as toxins from harmful algal blooms, viruses, bacteria, and protozoa (Clement et al., 2012). Awareness of these contaminants within the research community has increased with the prevalence of biological and chemical contaminants in the basin (Fig. 2) and specific areas of concern have been identified and subjected to the remedial action plan program for restoration and management (Krantzberg, 2012; Fig. 3).

Eutrophication and algae

Phosphorus (P) and nitrogen (N) have been identified as the main nutrients that drive eutrophication, the excessive growth of aquatic plants and algae that causes degradation of habitats, hypoxia in benthic waters, fish kills, and beach closures due to cyanobacterial blooms (Schindler, 2012). One of the most significant symptoms of eutrophication in the Great Lakes basin was the emergence of anoxic zones in the central basin of Lake Erie in 1968, although anoxic events in the

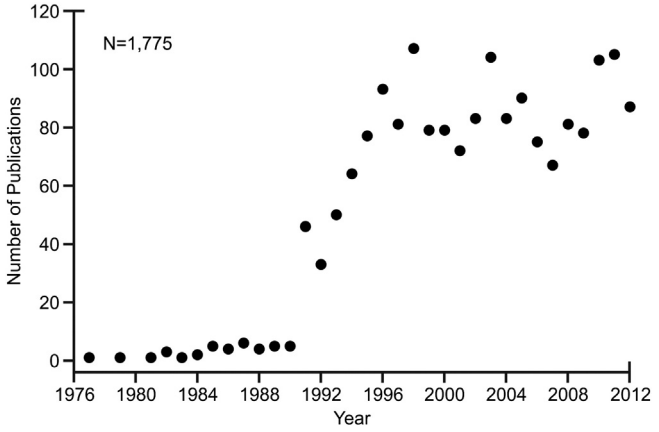

Fig. 2. Sample number of scientific publications pertaining to biological and chemical contaminants in the Great Lakes basin since the GLWQA was commissioned. Literature search was conducted using ISI Web of Knowledge with the following search criteria: Topic = Contamin* AND Topic = Great Lakes*. All search results were verified for accuracy.

Please cite this article as: Cornwell, E.R., et al., Biological and chemical contaminants as drivers of change in the Great Lakes–St. Lawrence river basin, J Great Lakes Res (2014), http://dx.doi.org/10.1016/j.jglr.2014.11.003