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Review

Multiple threats and stressors to the Athabasca River Basin: What do we know so far?

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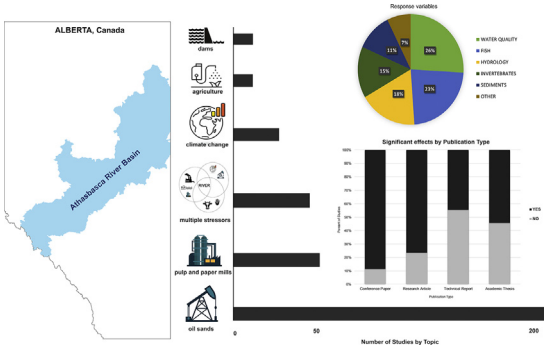
HIGHLIGHTS

- The majority of studies assessed only the effects of single stressors.
- Chemical contamination from oil sands mining dominated most publications.
- Contradictory conclusions were reported regarding significant effects.
- Substantial knowledge gaps on multiple stressors effects need further research.

GRAPHICAL ABSTRACT



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ABSTRACT

Over the last five decades, the Athabasca River Basin in Alberta, Canada, has been subjected to a wide range of environmental stressors from diverse human developments. This has resulted in an escalation of government, academic, industry and community-based monitoring and research efforts. However, despite all the attention received, a comprehensive synthesis of what has been studied is lacking, in particular, in relation to the efforts examining single versus multiple stressors. Based on a systematic literature review, we found 386 publications from 1969 to 2018 on the Athabasca River focusing on single stressors (68.4%) compared to multiple stressors (31.6%). There was a significant shift in the focus of studies between the 1990s and present from assessing threats of pulp and paper developments to those related to oil sands activities, with studies most predominantly addressing chemical stressors. Despite these efforts, there remain significant knowledge gaps regarding the cumulative effects of multiple stressors, particularly on biological and ecological endpoints. Correspondingly, a wide range of contradictory conclusions were reported regarding the ecological, regulatory and societal significance of the reported environmental impacts, highlighting both the complexity and often lack of standardization of approaches used. This emphasizes the need for improved integration of monitoring and research activities that are hypothesis driven, have clear objectives, and are better aligned with environmental management processes and decisions.

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Contents

1. Introduction

Anthropogenic impacts in Canada's watersheds have been growing rapidly in the last decades (Schindler, 2001; Schindler and Donahue, 2006; Squires et al., 2010). The Athabasca River Basin in Alberta, in particular, has been subjected to the accumulation of many threats that are translated into multiple stressors (e.g. urban development, forestry, municipal and industrial waste water discharges, oil sands developments, agriculture, and mining) (Bonnell and Keith, 2000; Munkittrick et al., 2000; Spaling et al., 2000; Culp et al., 2001; Dubé, 2003; Alberta Government, 2012, Squires et al., 2013). Consequently, studies on the direct and indirect effects of many of these stressors have increased substantially, as policy-makers, resource managers, aboriginal communities, scientists, industry, and the public have become increasingly aware of the many environmental issues these threats may pose (e.g. Lowell and Culp, 1999; Gummer et al., 2000; Dubé et al., 2006). This body of scientific information has mainly been focused in understanding the effects of individual stressors, their associated abiotic alterations, and their biological and ecological consequences (e.g. Kelly et al., 2009; Arciszewski et al., 2017a; Arens et al., 2017; Shotyk et al., 2017). Few studies have used quantitative evidence to assess the cumulative effects of multiple stressors, despite the existence of a large conceptual knowledge base in aquatic ecology (Nõges et al., 2016).

Due to the complexities associated with many developments and related environmental issues, the federal and provincial governments, industry, as well as community-based groups have been monitoring and conducting research on water quality, quantity, and biological/ecological endpoints since the 1960s in Athabasca River Basin (Squires et al., 2010). However, despite large data collection efforts over many decades, causal mechanisms linking the different environmental components studied and the endpoints being monitored, remain elusive. In addition, an integrative assessment of the effects of multiple environmental stressors and the potential cumulative impacts in the basin as a whole is necessary. Few studies have made an effort to assess cumulative effects from headwaters to the Peace-Athabasca Delta (NRBS, 1996; Environment Canada et al., 2004; Squires et al., 2010), while others have been focused on multiple stressors but only on specific, localized reaches of the Athabasca River Basin (e.g. Government of Candada, 1997; CEMA, 2010; RAMP, 2010; JOSM, 2012). Interestingly, the impact assessment literature and First Nations groups have suggested repeatedly that greater consideration should be given to the cumulative effects of multiple forms of development (see Hegmann et al., 1999; CCME, 2009; Seitz et al., 2011; Noble et al., 2014).

A key challenge that remains is that the monitoring data is spread amongst various sources (e.g. government departments and agencies, academia, industry, stakeholder organizations) and exists in a range of formats (e.g. government and industry reports, research articles, regulatory data reports), making it very difficult to compile in a manner that allows for a holistic and comprehensive synthesis of the frequency, magnitudes, and duration of the multiple stressors that have been affecting this watershed. This is a prominent issue as the basin holds significant environmental, cultural and economic importance, supporting First Nation and Metis groups, providing water to municipalities and industries, and is fundamental to the development of the multibillion-dollar oil sands mining industry (Squires et al., 2010).

Systematic reviews have been widely used and formalized in biomedical literature and social sciences (Lowry et al., 2013), and they are increasingly used in conservation biology and applied ecology (e.g. Stewart et al., 2005; Kettenring and Adams, 2011; Lowry et al., 2013). They differ from narrative reviews in that they follow a strict methodology, being more comprehensive, minimizing the chance of bias and improving aspects such as transparency and reliability (Stewart et al., 2005). In addition, they have been considered particularly well suited for evaluating the effectiveness of environmental management actions and a solid foundation for evidence-based adaptive natural resource management (Doerr et al., 2015). We did not attempt to quantify the results in a meta-analysis, but rather to gain a better understanding of what has been monitored/studied, specially focusing in single vs. multiple stressors and their cumulative effects. The purpose of categorizing the literature was to address the following elementary questions: what has been published regarding the anthropogenic impact in the Athabasca River Basin? What were the main threats and key stressors addressed? Was any evidence of a significant effect found?

The primary goal of this literature-based analysis was to evaluate the state and nature of the monitoring and research publications regarding the anthropogenic threats and stressors affecting the Athabasca River Basin and to identify knowledge gaps. The secondary goal was to create a publicly accessible database of this literature for future research. To assess the current state of knowledge, we carried out a systematic review by identifying and characterizing the primary environmental subjects, organisms and stressors studied, as well as their ecological consequence.

2. Methods

2.1. Study area

The Athabasca River Basin is 157,000 km^2 in area and accounts for approximately 22% of Alberta's landmass (Gummer et al., 2000). It is fed by ten smaller watersheds or sub-watersheds that flow into the