Received: 17 December 2020 | Accepted: 14 May 2021

DOI: 10.1002/2688-8319.12079

REGISTERED REPORT STAGE 1: STUDY DESIGN

Ecological Solutions and Evidence | BRITISH ECOLOGICAL SOCIETY

How do natural changes in flow magnitude affect fish abundance and diversity in temperate regions? A systematic review protocol

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Funding information
Natural Sciences and Engineering Research Council of Canada; Fisheries and Oceans Canada; Carleton University

Abstract

1. Natural flow regimes play important roles in maintaining the ecological integrity and diversity of aquatic ecosystems. Wildlife has adapted over time to the natural dynamics of their environment, including changes in flow regimes. Changes in flow, including changes in magnitude, frequency, duration, timing and rate of change, may affect the physical characteristics of aquatic habitats, access to habitats, food availability, population dynamics and community composition.
2. Given the importance of natural flow regimes for fish, it is necessary to understand the extent to which natural flow regimes alter fish abundance and diversity. Here we present a protocol for a systematic review that will estimate how fish abundance and diversity are affected by natural variation (resulting from climatic variability and broad-scale drivers such as climate-induced change) in flow.
3. This systematic review will use evidence published before 2016 that was identified in a recent systematic mapping exercise on the broader topic of flow regime change impacts (both natural and anthropogenic) on direct outcomes of freshwater or estuarine fish productivity. An updated English language search will be performed using six bibliographic databases, Google Scholar and networking tools to include commercially published and grey literature that has been published after 2016. Eligibility screening will be conducted at two stages: title and abstract, and full-text. We will include all studies that evaluate the effect of natural changes in flow magnitude on fish abundance (broadly defined to also capture density and biomass metrics) and species diversity (broadly defined to also capture species richness and composition metrics). Any freshwater or estuarine fish species in temperate regions will be considered.
4. Included eligible studies will be assessed for study validity. We will extract information on study characteristics, intervention/comparator details, measured outcomes

Handling Editor: Thomas Neeson

and effect modifiers. A narrative synthesis will describe the quantity and characteristics of the available evidence, and where sufficient numbers of similar studies are available, a meta-analysis will be conducted to estimate an overall mean and variance of effect.

KEYWORDS
climate change, discharge, drought, evidence synthesis, flood, flow modification, flow variability, seasonal variation

1 | INTRODUCTION

Rivers and streams are often described as the arteries of the Earth as they play critical functions for both aquatic and terrestrial ecosystems, as well as providing important services for humans. A defining aspect of rivers and streams is that they flow and the various components of their flow regime (including magnitude, frequency, duration, timing and rate of change of flow) not only play an important role in maintaining the ecological integrity of aquatic ecosystems but also lead to highly diverse types of fluvial ecosystems (Bunn and Arthington 2002; Olden & Poff, 2003; Poff et al., 1997). For example, the Mekong, one of the largest rivers in the world, has an annual flood cycle that submerges a large portion of the Delta, causing the water to flow backwards upstream into the Tonle Sap Lake. The lake varies between 1 and 14 m in depth during the dry and wet seasons, respectively (Mekong River Commission, 2005). Wildlife, and fish in particular, have adapted over time to the natural dynamics of their environment, including variable natural flow regimes (Lytle & Poff, 2004). Indeed, flow determines the template upon which life history strategies of fish populations have evolved (Lytle & Poff, 2004). Thus, an important concern for water resource managers is to better understand how natural changes in flow regime influence fish abundance and diversity.

The effects of natural changes in flow resulting from climatic variation (i.e. seasonal variation, floods, and droughts) can affect fish populations by causing changes in physical habitat, access to habitat, behaviour, food availability, energy expenditure, population dynamics and community composition (Bunn & Arthington, 2002; Humphries et al., 2008; Lytle & Poff, 2004). For example, some species time reproduction to coincide with peak flows, whereas other species within the same system reproduce in low flow conditions only (Górski et al., 2010; Humphries et al., 1999; Hoagstrom and Turner, 2015). This reduction in temporal overlap for reproduction reduces competition for critical resources (Skoglund et al., 2011), and thus changes in flow, even when due to natural causes, can have a direct impact on recruitment. In another study, Warren et al. (2009) found that the timing and magnitude of spring high flows in the Catskill Mountain streams could increase the abundance of spring-spawning salmonids, decrease the abundance of fall-spawning salmonids, or both. The authors also predicted that if larger, more frequent and earlier spring floods continue to occur as a result of global environmental change, differential survival of species are likely to cause shifts in community composition.

Additionally, climate change is predicted to have severe repercussions on natural flow regimes around the globe. For example, simulated 100-year floods are predicted to increase, both in magnitude and frequency, by the 2080s in most Midwestern rivers of the United States, with annual peak flows shifting earlier (Byun et al., 2019). In Alaska, the permafrost is expected to degrade rapidly and alter subsurface flows and flow paths (Douglas et al., 2013). Given the importance of natural flow regimes for fish and the pressing nature of climate change, water resource and fisheries managers are now faced with the daunting task of understanding the extent to which natural flow regimes alter fish abundance and diversity. In turn, this will enable managers to predict how fish populations are likely to be affected by climate-induced flow changes in the near future.

Evidence syntheses to date have largely focused on (1) how anthropogenically altered flows specific to hydropower or water taking activities impact ecosystem dynamics (e.g. Gillespie et al., 2015; Murchie et al., 2008; Webb et al., 2013; and a forthcoming systematic review, see Harper et al., 2020); and (2) how natural changes in flow (i.e. floods and droughts) affect fish ecology in specific geographical areas (e.g. South Atlantic Region of the USA, McManamay et al., 2013 ; Europe, Piniewski et al., 2017). To our knowledge, there is currently no comprehensive global evidence synthesis relating to better understanding how changes to flow components originating from climatic variability (including but not limited to extreme hydrological events) affect fish abundance and diversity. For the purpose of this review, we consider natural flow variation to be changes in flow magnitude due to climatic variation (e.g. increases in flow magnitude due to flooding because of precipitation, decreases in flow magnitude due to drought because of increased ambient temperature and/or decreased precipitation, or general natural variation such as increases in flow = magnitude of baseflows). Because climatic variability could be more related to broad-scale drivers such as climate change, and these effects are difficult to tease apart, we will consider both as relevant to the topic of this review (hereafter referred together as natural causes), acknowledging that climate change can be attributed to both natural and human-induced causes. We also acknowledge that most rivers worldwide do not flow naturally (Grill et al., 2019; Su et al., 2021), making it necessary to understand how changes in flow in these anthropogenically modified systems impact fish productivity (see, e.g. a forthcoming systematic review on this topic, Harper et al., 2020). However, there is also a necessity for understanding how changes in flow in natural (or near-natural) systems affect fish productivity, because

(1) fish in these systems may still be subject to management actions, which may be optimized with a better understanding of flow regime impacts, (2) these natural systems are likely to be impacted by climate change, which will inevitably affect flow regimes and (3) characterizing similarities among fish-flow relationships due to different causes of flow alteration will aid in the development of general principles for flow regime management (Arthington et al., 2006; Poff et al., 2010).

1.1 | Topic identification and stakeholder involvement

At the request of a Canadian natural resource management agency and regulator (i.e. Fisheries and Oceans Canada, DFO), a systematic map was recently conducted (Rytwinski et al., 2020) to provide a summary of the existing literature base on the impacts of changes in flow regime on fish productivity in temperate streams. Temperate streams were the focus of the systematic map as these were most relevant to the Canadian context. However, it was recognized by Rytwinski et al. (2020) that temperate regions outside of Canada could provide additional relevant information as well as increase the amount of information from which to review, hence all temperate regions globally were included in the mapping exercise, and we are proposing to do the same here for this systematic review. Fish productivity was broadly categorized in terms of abundance, diversity, growth, migration, reproduction and survival. The literature included freshwater and estuarine fish in temperate regions. Although procedurally similar to a systematic review, systematic maps do not aim to provide a quantitative or qualitative answer to a particular question, but instead, an overview of research that has been undertaken, where, and how (Haddaway et al., 2016; James et al., 2016). A total of 1368 relevant studies were identified, describing a range of flow regime alterations and fish productivity responses. The map followed the Collaboration for Environmental Evidence (CEE; https://environmentalevidence.org/) guidelines for systematic mapping (CEE, 2018; i.e. guidelines and standards for the planning and conduct of environmental management evidence syntheses adapted from methodologies developed and established in the health sciences), whereby the quantity and key characteristics of the available evidence were described, and evidence clusters and knowledge gaps were identified.

From the map, 11 potential subtopics were identified as areas that had sufficient coverage to allow systematic reviewing. The subtopics "the effect of natural changes in flow magnitude on fish abundance (which included abundance, density, and catch per unit effort (CPUE) metrics)" and "the effect of natural changes in flow magnitude on fish community diversity and species richness (which included composition metrics)" were identified as candidates for full systematic reviewing based on the presence of sufficient evidence and the relevance of the topic to Canadian stakeholders. Since the original systematic map searches were conducted in 2017, additional studies on this topic are likely to have been published.

An Advisory Team made up of stakeholders and experts including academic scientists from Canada and Australia (two members), staff from DFO, specifically the Fish and Fish Habitat Protection Program (two members), and Science Branch (two members), as well as staff from hydropower industry (one member) and non-profit organizations (one member) was established and consulted during this review process. The Advisory Team was consulted in the development of the inclusion criteria for article screening and metadata extraction strategy and will continue to participate in this systematic review through to completion.

2 | OBJECTIVE OF THE PROTOCOL

The objective of the proposed systematic review is to clarify, from the existing literature, how fish abundance and diversity are impacted by alterations in flow magnitude due to natural causes, that is climatic variability and climate-induced changes.

2.1 | Primary question

How do natural changes in flow magnitude affect fish abundance and diversity in temperate regions?

2.2 | Components of the primary question

Subject (population): freshwater and estuarine fish in temperate regions

Intervention/exposure: changes to flow magnitude due primarily to natural causes (i.e. seasonal, climatic variability and climate-induced changes)

Comparator: evaluations on this topic are often conducted without a comparator (i.e. no intervention or alternate levels of intervention). As such, no studies will be excluded based on the presence or absence of a comparator.

Outcomes: measures of changes in abundance (broadly defined in terms of abundance, density, CPUE, biomass, yield, etc.) and diversity (broadly defined in terms of species richness, diversity, composition, etc.)

2.3 | Secondary question

To what extent do factors (e.g. fish taxa, outcome metrics, life history characteristics, study design and setting) influence the potential impact of changes in flow magnitude due to natural causes on fish abundance and diversity?

2.4 | Hypotheses and predictions

Primary question: Given that in the context of fluvial systems, flow determines the template upon which life-history strategies of fish populations have evolved (Lytle & Poff, 2004), it is hypothesized that

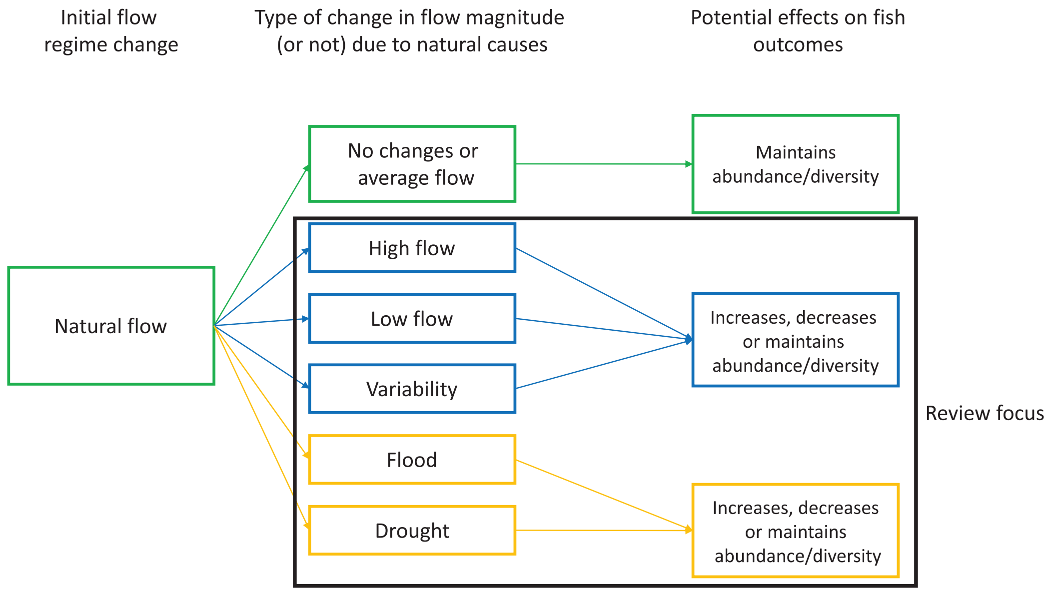

FIGURE 1 Conceptual model linking changes in flow magnitude due to natural causes to potential changes in abundance and diversity of freshwater fish. Green pathway: no changes or average flow maintained resulting in little effect on fish abundance and diversity (this pathway is not included in this systematic review). Blue pathway: changes in high flow magnitude, low flow magnitude, and variability in flow magnitude resulting in a change (increase or decrease) or maintenance of fish abundance and diversity. Yellow pathway: increased flow magnitude from flooding or decreased flow magnitude from droughts resulting in a change (increase or decrease) or maintenance of fish abundance and diversity (although most responses are expected to lead to decreases in fish abundance and diversity; with droughts expected to have greater negative impacts than floods). Potential effects on fish outcomes are based on existing evidence (see, e.g. McManamay et al., 2013; Piniewski et al., 2017; Maxwell et al., 2019)

changes in flow due to natural causes will affect fish abundance and diversity (see Figure 1 for a conceptual model). The direction and magnitude of this effect on fish abundance and diversity are predicted to depend on the direction and magnitude of the change in flow magnitude, but also on other metrics like species and life history characteristics. In contrast to anthropogenic flow alterations, which largely have negative impacts on fish outcomes (Poff & Zimmerman, 2010; McManamay et al., 2013), natural unaltered systems have a high inherent variability, and thus effects on fish outcomes are less predictable. Given the natural variability of fluvial systems, it would therefore be expected that fish responses to flow alterations vary widely, regardless of direction and magnitude of changes in flow (McManamay et al., 2013). As such, it is difficult to make predictions for how fish species/populations/communities are likely to respond to changes in flow magnitude. For example, increased flow magnitude, decreased flow magnitude and flow magnitude variability due to natural variation have been found to have both positive and negative impacts on fish outcomes (McManamay et al., 2013). Nonetheless, high flow and flow variability may be expected to have largely positive effects on fish abundance and diversity, while low flow may be expected to have largely negative effects on fish abundance and diversity. The occurrence of extreme events, like floods and droughts, are likely to have generally negative impacts on fish outcomes with decreased abundance and diversity (Piniewski et al., 2017; Maxwell et al., 2019), though the severity of the events may not be an important factor influencing fish responses (Piniewski et al., 2017). Droughts are expected to have greater negative impacts than floods (McManamay et al., 2013).

Secondary question: Fish responses to changes in flow magnitude are expected to vary depending on secondary factors, like fish taxa or life history characteristics. For example, salmon are highly flow-oriented and have strong swimming abilities, but roach do not. As such, increased flow may yield an increase in the abundance of salmon, but a decrease in the abundance of roach if roach cannot tolerate or are displaced (e.g. swept away) from the increase in flow magnitude. We may also expect that increases in abundance are not necessarily accompanied by increases in diversity given the expected taxa-specific responses to flow. For example, a study in North America found that increases in spring peak flows were associated with increased abundance of opportunistic species (i.e. small-bodied fishes with extended spawning seasons and early maturation), while the abundance of periodic species (i.e. large-bodied species with delayed maturation and long lifespans) and equilibrium species (i.e. intermediate-sized species that display parental care) decreased (Hitt et al., 2020). Furthermore, river systems in different climates and/or ecoregions may vary in response to alterations in flow magnitude. For instance, an extreme flood event in a mountainous (or upland) river system may result in negative responses in fish abundance as it is likely more disturbance-related; whereas such an event in a coastal plain river system could result in positive impacts on fish outcomes if the event provides important lateral floodplain habitat and refuge for fish (McManamay et al., 2013).

Systematic reviews with accompanying quantitative synthesis aim to generalize ecological relationships and explore differences in individual study characteristics and heterogeneity in results (CEE, 2018). Previous reviews on ecological responses to anthropogenic flow alterations determined that unambiguous, transferable empirical relationships between flow components and species responses were not possible given the state of the literature base a decade ago (Poff & Zimmerman, 2010), and that relationships between ecological responses and natural changes in flow were highly context-dependent (McManamay et al., 2013). Now, with some time past, and taking a more systematic approach to gathering relevant evidence, a global scope, and focusing on a single flow component (i.e. magnitude), we are interested to determine whether strong signals in fish outcomes to alterations in flow magnitude due to natural changes will emerge.

3 | MATERIALS AND METHODS

This review will follow, as closely as possible, the guidelines and standards for systematic reviews (CEE, 2018) and conform to RepOrting standards for Systematic Evidence Syntheses in environmental research (i.e. ROSES; detailed forms for ensuring evidence syntheses report their methods to the highest possible standards; see Haddaway et al., 2018 and completed forms in Birnie-Gauvin et al., 2021a).

3.1 | Searching for articles

3.1.1 | Selection of studies identified in the systematic map

Much of the evidence on which this systematic review will be from the recently completed systematic map on the effects of flow alteration on fish productivity previously mentioned (Rytwinski et al., 2020). In this map, a total of 1368 relevant studies were identified, of which 188 and 41 considered natural alterations to flow magnitude and a fish abundance or biomass metric, respectively, and 68 considered natural changes in flow magnitude on fish diversity metrics. The systematic map searched for commercially published (e.g. academic literature from journals or books) and grey literature (e.g. reports, government documents, white papers) using six publication databases (searches performed in July 2017), one search engine (search performed in July 2017) and 29 specialist websites (search performed in February 2017). In addition, reference sections of 297 relevant reviews and all articles included at full-text screening were hand searched for relevant titles that were not found using the search strategy. Calls for evidence were also issued to target grey literature through relevant mailing lists, social media, and the networks and colleagues of Advisory Team members (calls performed in February and November 2017). In summary, the systematic map included all articles available from 1900 to July 2017.

The systematic map informing this systematic review identified studies considering the impacts of alterations to any flow component on fish productivity (Rytwinski et al., 2020). The search string used in the systematic map can be found in Birnie-Gauvin et al. (2021b).

TABLE 1 Search string that will be used to update searches from 2017 onward (in Web of Science Core Collection format)

Component	Search string
Population terms	TS = [(Fish*) AND ("Fresh water" OR Freshwater OR Stream$ OR Water$ OR River$ OR Fluvial OR Estuar* OR "Climate change" OR Lake$ OR Wetland$ OR Marsh*)]
	AND
Intervention/exposure terms	(Flow* OR Discharg* OR Drought$ OR Flood* OR Intermittent)
	AND
Outcome terms	(Productivity OR Biomass OR Abundance$ OR Densit* OR Yield$ OR "Ecological response" OR "Ecosystem response" OR "Biotic response" OR Richness OR Composition)
	NOT
Exclusionary terms	(Aquaculture OR Farming OR Microplastic$ OR Mercury OR Copepod$)

3.1.2 | Search update

Search terms and languages

To identify more recently published literature on the specific topic of this systematic review, a search update will be conducted using a subset of the search terms used for the systematic map (Table 1). We conducted a scoping exercise in September 2020 to assess original search terms from the map and alternative search terms related to this review topic (see Birnie-Gauvin et al., 2021b). The population, intervention/exposure and outcome components of the search, will be combined with Boolean operators 'AND' and/or 'OR'. The operator 'NOT' will be used to decrease the number of non-relevant studies found by the search. The asterisk (*) is a 'wildcard' that represents any group of characters (including no character), while the dollar sign ($) includes zero or one character. Quotation marks are used to search exact phrases (e.g. 'freshwater' includes the exact phrase freshwater as well as the hyphenated fresh-water).

The search update will only cover literature published since January 2017, so a limited number of articles is expected (see Birnie-Gauvin et al., 2021b) for the number of records retrieved by scoping searches using this search strategy). Duplicates identified from the overlapping search dates between the mapping exercise (search date end July 2017) and the search update (search date start January 2017) will be removed prior to screening. English search terms will be used to conduct all searches in all databases and search engines. No language or document type restrictions will be applied during the search (i.e. if an abstract is in English but the article is in a different language), but only English language literature will be included during the screening stage. All bibliographic databases will be accessed using Carleton University's institutional subscriptions as outlined in Supporting information file 1.

When complex search strings are not accepted, search strings will be customized and included in the final report as was done in the original systematic map.

Publication databases

The following online databases, originally searched in the map, will be accessed during the search update:

1. Federal Science Library (Canada): Canadian government books, reports, government documents, theses, conference proceedings, and journal titles;
2. ProQuest Dissertation & Theses Global: a collection of dissertations and theses from around the world, spanning from 1743 to the present;
3. Science.gov: U.S. Federal Science;
4. ISI Web of Science Core Collection: multidisciplinary research topics including journals, books, proceedings, published data sets and patents;
5. Scopus: abstract and citation database of peer-reviewed literature including journals, books and conference proceedings; and
6. AGRICOLA (Agricultural Research Database): U.S. Department of Agriculture's National Agricultural Library.

Search engines

The same search engine, Google Scholar, originally used in the map will be used to perform internet search updates. Three simplified search strings will be used in the search engine: (1) Fish AND Drought AND (Productivity OR Biomass OR Abundance OR Density OR Yield OR Richness OR Composition); (2) Fish AND Flood AND (Productivity OR Biomass OR Abundance OR Density OR Yield OR Richness OR Composition); and (3) Fish AND Flow AND (Productivity OR Biomass OR Abundance OR Density OR Yield OR Richness OR Composition) (see scoping exercise for Google Scholar in Birnie-Gauvin et al., 2021b). The first 150 hits from each string (sorted by relevance) will be screened for appropriate fit with the review question. However, if the reviewer noticed that the level of relevance of each article significantly declines before screening the first 150 articles, the reviewer will stop when the relevance significantly declines (as per suggested by Livoreil et al. (2017).

Specialist websites

Twenty-nine specialist organization websites were searched in the systematic map using abbreviated search terms (see Rytwinski et al., 2017). Because it is often not possible to specify a date filter using the built-in search facilities of these websites, a search update will not be conducted for specialist websites.

Supplemental searches

The reference sections of all articles included at the full-text screening stage and relevant reviews found during the search update will be hand searched to evaluate articles that have not been found using the search update strategy. Only additional articles from 2017 onward will be considered. Authors of unpublished references will be contacted to request access to the full article and the Review Team will contact authors of any articles that are unobtainable through library licenses or interlibrary loans to gain access to the full article. Advisory Team members will be consulted for advice for new sources of information. Additionally, social media and email will be used to reach out to experts and practitioners in the field for recommendations and provision of relevant unpublished information and to alert the community to this systematic review. To increase the chances of capturing previously missed unpublished relevant information from these expert and practitioner recommendations, no date restriction will be applied. Sources of information retrieved through these supplemental searches will be recorded in the database.

Estimating comprehensiveness of the search

Since the review will follow the same basic search strategy and use a similar search string to the systematic map, we will not repeat tests of the comprehensiveness of the searches that were originally performed therein (i.e. the search results were checked against a benchmark list of 13 relevant papers provided by the advisory team to ensure all articles were captured using the search strategy). The search update will cover literature published since 2017. As such we are not anticipating a large number of new articles. Additionally, the majority of articles included as relevant in the systematic map (using a much broader eligibility criterion than the focus of this review) were identified through databases and search engines (1055/1199 articles; 88%), with relatively few articles identified through website searches (36/1199; 3%). The remaining included articles were identified from the reference sections of reviews and included articles, or through calls for evidence (108/1199; 9%). We, therefore, consider it sufficient to base the search update on the same databases and search engines as used in the systematic map (described in Rytwinski et al., 2017, 2020) and complemented with the supplemental searches described immediately above.

3.2 | Article screening and study eligibility criteria

3.2.1 | Screening process

Articles will be screened at two distinct stages: (1) title and abstract and (2) full-text. Documents found through databases and search engines will be screened at title and abstract. Before screening begins, reviewers will undertake consistency checks using a random subset of approximately 5% of all articles at both stages to ensure consistent and repeatable decisions are being made. The results of the consistency checks will be compared between reviewers, and all discrepancies will be discussed to understand why an inclusion/exclusion decision was made. Revisions to the inclusion criteria will be made as necessary. Where the level of agreement is low (i.e. below 90% agreement), further consistency checking will be performed on an additional set of articles and then discussed.

Following consistency checks (i.e. when the agreement is ≥ 90%), articles will be screened independently by reviewers. Articles found through calls for evidence or from the reference sections of included or review articles will be screened at full-text but will not be included inconsistency checks. If the reviewer is uncertain whether to include an article at any screening stage, they will tend toward inclusion to the next stage. If there is further doubt, the Review Team will discuss those articles as a group and come to a decision. Justification for inclusion or exclusion will be explained and recorded using EPPI-Reviewer Web (https://eppi.ioe.ac.uk/EPPIReviewer-Web/home), and a list of studies rejected at full-text will be provided in an additional file together with the reason for exclusion. Digital media will be screened, when they are available online without the need for purchasing the media or having specialized pay-for-use software to view it. The Interlibrary Loans program at Carleton University will be used to acquire hard or digital full-text copies of any articles that are included once the title and abstract screening has occurred. Reviewers will not screen studies (at title and abstract or full-text) on which they are an author.

3.2.2 | Eligibility criteria

The following predefined criteria, modified from the systematic map, will be used when assessing relevance and deciding on inclusion or exclusion of articles.

Eligible populations

Any fish species in North (23.5 °N–66.5 °N) or South (23.5 °S–66.5 °S) temperate regions. This includes any resident (i.e. non-migratory) or migratory fish species, including diadromous species (i.e. fish that migrate between fresh and saltwater). Any life stage will be considered. Populations may include those that were once stocked (but are no longer being stocked) or invasive and became established in the waterbody. Only studies located in freshwater or estuarine fluvial (i.e. water moving via gravity) ecosystems, such as lakes, rivers, streams, wetlands, and marshes will be included.

Eligible intervention/exposures

Articles that describe variability or a change in the magnitude of flow. Magnitude can be defined as the amount of water moving past a fixed location per unit time (Poff et al., 1997). Magnitude is therefore a measure of discharge and can refer to either relative or absolute discharge and can be expressed in a variety of units. The review focus will be on natural causes of variation or a change in flow magnitude that would directly (or near directly) affect fish including those originating from climatic variation such as seasonal changes (e.g. rainfall, snowmelt, ice), droughts and floods, that operate on annual or shorter time scales. Additionally, the review will include, when available, longer-term climate-induced changes in flow that would have delayed but potentially significant impacts on fish communities. These could include natural (or near-natural) systems (i.e. those relatively unimpacted by direct human pressure) as well as human-modified systems (as long as no anthropogenic changes in magnitude were made during the study period). We will exclude drivers of change related to in-stream channel engineering, reduction in river length, construction of dikes, weirs, operation of hydropower plants and reservoirs, urbanization, transport infrastructure, deforestation, ditch construction, agricultural management practices, drainage of wetlands and agricultural areas, and construction of flood retention basins. Articles that report unspecified multiple components affecting flow (i.e. do not report effects of components separately to isolate individual impacts of the flow components) will also be included; however, a sensitivity analysis will be carried out to investigate the influence of including such articles in the quantitative analysis when the evidence-base allows.

Eligible comparators

Relevant comparators include (1) similar sections of the same waterbody that are not affected by a naturally caused change in flow magnitude (e.g. upstream condition); (2) separate but similar water bodies without a naturally caused change in flow magnitude; (3) before a naturally caused change in flow magnitude within the same waterbody; or (4) time-series data within the same waterbody. However, this review will include all relevant studies, with or without a comparator.

Eligible outcomes

Studies must report measured effects that indicate the potential for a change in fish abundance or diversity (i.e. direct flow-fish responses). Outcomes include those related to abundance, density, CPUE, biomass, yield, and species richness, composition, or diversity indices. Only studies that consider a direct response (outcome) of some aspect of abundance or diversity listed above will be included. Studies that evaluate some other direct response of fish productivity (e.g. growth, survival, migration) or that consider indirect responses to altered flow will be excluded. For example, if authors make an indirect link between the measured outcome of altered flow (e.g. growth of aquatic plants) and its 'potential' impact on fish (e.g. diversity), the article will not be included for further review.

Eligible types of study designs

It was recognized that study designs included in this review will likely not fit the typical Before/After (BA), Control/Impact (CI), Before/After/Control/Impact (BACI), or Randomized Controlled Trials (RCT) structure. Therefore, we aim to include all primary field-based studies that include quantification of fish abundance and diversity outcomes in relation to natural variability in flow magnitude, including the above-mentioned designs, as well as a Reference Conditional Approach (RCA), Normal Range (NRange), and temporal (i.e. time series) or spatial trend designs. Studies will be excluded if they use a single point of time with no comparison to another site, or a single impact site with no before-treatment data. Theoretical modelling, reviews and policy discussions will be excluded.

Language

Only English-language literature will be included during the screening stage. This limitation is because we do not have the resources to conduct non-English searches. In the systematic map, a limited number of non-English articles with English abstracts (62 out of 18,231 articles identified through database searching; 0.34%) were identified and excluded based on language (Rytwinski et al., 2020). Consequently, we do not expect that our updated search will return a significant number of non-English articles. Whether any of these articles would have met all inclusion criteria for the systematic map or this systematic review is unclear; however, still, we acknowledge that the ability to include non-English articles would strengthen the accuracy of resulting syntheses.

3.3 | Study validity assessment

Articles that are found to be relevant to this review at the full-text screening stage will then undergo a study validity assessment. This critical appraisal will be carried out on a study-by-study basis rather than article-by-article since a single article could report more than one observation. The focus of the assessment will be on the internal study validity (i.e. susceptibility to bias) and study clarity. External validity (study generalizability) will not be assessed; instead, generalizability will be captured during screening.

Data on criteria outlined below will be extracted from each relevant study in a detailed and transparent manner and entered in an MS-Excel worksheet. Critical appraisal will be done by at least two reviewers on a subset of articles and, when unsure, the reviewers will come together to discuss. Final decisions regarding doubtful cases will be taken by the Review Team as a whole. If any studies have the following deficiencies listed below, study validity will be classified as low (i.e. meaning susceptibility to bias will be considered high):

- *No (or unclear) use of a temporal or spatial comparison (i.e. temporal/spatial trend designs).*
- *No (or unclear) replication (i.e. < 2 independent experimental/observational units; the level of replication at which the intervention was administered/the exposure experienced).*

For studies that are not considered to have any of the deficiencies listed above, the study will be considered to have either medium or high study validity (i.e. medium or low susceptibility to bias, respectively). If any of the criteria listed below apply, study validity will be classified as medium. If none of them apply, study validity will be considered high.

- *Replication is less than ideal (i.e. pseudoreplication).* There are at least two experimental/observation units but there is a lack of independence between these units.
- *The intervention cannot be clearly interpreted*. Either (1) it is clear that a change in flow magnitude has occurred but either no quantitative data on magnitude is reported, or the quantitative data is difficult to interpret (e.g. averaged across intervention and control sites), or (2) the study compares an unimpacted stream (or section of a stream) to an impacted stream (i.e. impacted via a natural hydrological event)], or reports unspecified multiple components affecting flow (i.e. do not report effects of components separately to isolate individual impacts of flows components).
- *Different/inconsistent (or unclear) sampling/measurement methods are used across sites (e.g. intervention and control sites) and/or time periods (e.g. gear type, timing or size of sample areas).*

Initial exploration of the available data on this topic suggests that most studies investigating the impacts of natural flow alterations on fish abundance and diversity are mensurative, where ecosystem responses are observed over time (Konrad et al, 2011), lacking true comparators (i.e. control sites or before data). These studies would therefore be characterized as having low study validity. While quantitative study designs using comparators are critically important to ensure reliability and robustness of evidence for impacts of interventions, arguments can be made regarding potentially important insights that could be gained from studies that measure responses to uncontrolled variation in flow that do not have proper comparators (when accompanied with an appropriate consideration for study validity). As such, no studies will be excluded based on this study validity assessment and when possible and appropriate, sensitivity analyses will be carried out to investigate the influence of study validity categories in the quantitative analysis. If the evidence base does not allow for a quantitative analysis of the influence of study validity, results of this assessment will instead be used to provide a basic overview of the robustness of the evidence and incorporated into the discussion of results and recommendations for future research needs and considerations.

3.4 | Data coding and extraction strategy

Meta-data from studies included in full-text will be extracted by the Review Team and recorded in an MSExcel spreadsheet that includes predefined coding. A draft version of the data extraction sheet is in Supporting information file 2. The extracted data will be used to assess the overall effect of alterations in flow magnitude associated with natural causes on fish abundance and diversity. When sufficient, good quality data exists, the information will be used in a meta-analysis. We will extract data on bibliographic information, study location and characteristics (e.g. geographic location, climate, waterbody name and type), study design details (e.g. study dates, study design), intervention/exposure and comparator details, outcome (i.e. abundance, biomass, diversity, richness, composition), sampling method(s) (e.g. type, size of sampling units), species (or species groups) and life history (e.g. genus and species names, life stage), effect modifiers (see below), study validity assessment results (see above) and study findings (qualitative description of flow magnitude effects) as reported by authors. This list may be expanded depending on the type and variety of included studies. Coding options within these key variables will be compiled in a partly iterative process, expanding the range of options as they are encountered during extraction.

Some quantitative outcome data that will be recorded include: sample sizes, outcomes (e.g. means, correlation coefficients), and measures of variation (e.g. standard deviation, standard error and confidence intervals). When information is presented in graphs, information will be extracted visually; however, if it is not possible to interpret the information, the corresponding author of the article will be contacted (via email or phone) if time permits, or imaging software such as WebPlotDigitizer (Rohatgi, 2015) will be used. When only raw data are included in the article, the Review Team will calculate summary statistics and will record how the calculations were conducted and what information was used. All extracted data will be made available as additional files. Reviewers will not extract data from studies for which they are an author.

To ensure data extraction is being conducted in a repeatable and consistent manner, reviewers will extract information from a random subset of articles (approximately 5–10% of articles included at full text) at the beginning of the process. The information will be compared, and any inconsistencies will be discussed with the Review Team members. If any disagreements occur the entire Review Team will discuss them, and modifications to the extraction codebook will be made where needed to ensure reviewers are extracting and interpreting data in the same manner.

3.5 | Potential effect modifiers and reasons for heterogeneity

Potential reasons for heterogeneity (i.e. factors other than flow that may cause variation among studies) will be identified and extracted from articles included at the full-text level of screening if reported in primary studies or available from authors. The following potentially effect-modifying factors will be considered and recorded:

- Type of comparator (i.e. spatial and/or temporal),
- Outcome metric (e.g. abundance: abundance, density, CPUE; diversity: Shannon diversity, Simpson diversity),
- Sampling methodology (e.g. active/passive gear, angling, telemetry),
- Study duration (i.e. length of time after a change in magnitude for which results were monitored),
- Biological factors (e.g. fish taxa and life stage),
- Other flow regime component alterations at site (e.g. flow timing, frequency, rate of change, duration),
- Waterbody characteristics (e.g. temperature, gradient, stream order),
- Land use (immediate surrounding landscape/watershed),
- Specific hydrological event (e.g. flood, drought),
- Catastrophic event (e.g. Yes, No) and
- Freshwater ecoregions (https://www.feow.org/).

Additional effect modifiers and reasons for heterogeneity may be identified and extracted from the studies as the review proceeds. This list of potential effect modifiers was compiled after consultation with stakeholders.

3.6 | Data synthesis and presentation

A narrative synthesis of data from all eligible articles in the systematic review will be generated. The synthesis will aim to be as visual as possible, describing the validity of the results and summarizing findings in tables and figures. The goal of this review is to create generalizable relationships between alterations of flow magnitude due to natural/climate causes and the impact on fish abundance and diversity and to identify factors that may influence the impact on fish responses (i.e. in what contexts do changes in flow magnitude due to natural/climate causes affect fish abundance and diversity) to better inform management decisions. All efforts will be made to conduct meta-analysis of the studies included in this review, when the study designs and evidence base allows. Separate subgroup analyses will be conducted for different fish outcomes: (1) abundance (combining, e.g. abundance, density, CPUE metrics); (2) biomass (combining biomass and yield metrics); (3) diversity (combining, e.g. Shannon and Simpson indices), (4) species richness and (5) composition. In the case that meta-analysis is possible (given a sufficient sample size of studies), study effect sizes will be standardized and weighted appropriately and analysis will take the form of random effects models. Meta-regressions or subgroup analysis of categories of studies will also be performed where sufficient studies report common sources of heterogeneity. The risk of publication bias will be assessed through funnel plots and sensitivity analysis using study validity categories will be carried out where possible. We will produce forest plots to visualize effect sizes and 95% confidence intervals from individual studies. Analyses will be conducted in R (R Core Team, 2020) using the *rma.mv* function in the metafor package (Viechtbauer, 2010).

4 | DISCUSSION

This study aims to produce a systematic review that will examine the effects of natural changes in flow magnitude (i.e. climatic variability and climate change) on fish abundance and diversity in temperate regions. Results from this proposed systematic review can serve to support new and ongoing research examining the relationship between flow and fish productivity outcomes. In particular, the systematic review findings can help to better predict fish responses to climate change-induced alterations in flow and support management and conservation efforts that could mitigate negative impacts.

ACKNOWLEDGEMENTS

The authors would like to thank several reviewers and collaborators who provided valuable insight to strengthen this review protocol including Stuart Bunn, James Crossman, Neil Fisher, Richard Kavanagh and Nick Lapointe. We also would like to thank the reviewers and all those involved in the systematic map that led to the identification of this topic. The review will be primarily supported by Fisheries and Oceans Canada. Additional support is provided by the Natural Science and Engineering Research Council of Canada and Carleton University.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

The manuscript was drafted by KBG and TR. All authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

Once the systematic review is completed following the protocol outlined here, data will be made publicly available via an online repository, such as Dryad or Figshare. ROSES form for this protocol can be found here: https://doi.org/10.6084/m9.figshare.14614221.v1 (Birnie-Gauvin et al., 2021a). Results from our search string scoping exercise can be found here: https://doi.org/10.6084/m9.figshare.14614170.v1 (Birnie-Gauvin et al., 2021b).

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/2688-8319.12079.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Birnie-Gauvin, K., Rytwinski, T., Harper, M., Taylor, J. J., Smith, A., Smokorowski, K. E., Turgeon, K., Bradford, M. J., & Cooke, S. J. (2021). How do natural changes in flow magnitude affect fish abundance and diversity in temperate regions? A systematic review protocol. *Ecol Solut Evidence*, *2*:e12079. https://doi.org/10.1002/2688-8319.12079