Environmental Evidence

SYSTEMATIC REVIEW PROTOCOL

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How do changes in flow magnitude due to hydroelectric power production affect fish abundance and diversity in temperate regions? A systematic review protocol

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Abstract

Background: Natural flow regimes are an essential component of healthy fluvial systems, but hydropower production alters flow components, disrupting natural processes and impacting species reliant on them. Establishing improved management of flow regimes requires a better understanding of how fish respond to altered flow components, such as flow magnitude. We recently conducted a systematic map to provide a summary of the existing literature base on the impacts of flow regime changes on direct outcomes of freshwater or estuarine fish productivity. Of those studies considering the impacts of flow magnitude changes due to hydropower, studies on fish abundance, biomass and diversity responses were identified as subtopics (i.e., knowledge clusters) that had sufficient coverage for further review. This systematic review proposes to estimate how fish abundance, biomass and diversity are affected by alterations in flow magnitude due to hydropower production.

Methods: This systematic review will use evidence identified during a systematic map process. An updated English language search will be performed using six bibliographic databases, Google Scholar, and networking tools to include academic and grey literature published after 2016. Eligibility screening will be conducted at two stages: (1) title and abstract, and (2) full-text. We will include all studies that evaluate the impact of changes to (or manipulations of) flow magnitude due to hydropower on fish abundance, density, biomass, yield, species richness, composition or diversity indices. The focus of this review will be on the downstream fluvial effects of flow magnitude changes and include hydroelectric facilities where water moves via gravity or by active pumping. Any freshwater or estuarine fish species or species group in temperate regions will be considered. Included eligible studies will undergo a critical appraisal that will assess the internal study validity. We will extract information on study characteristics, intervention/exposure and comparator details, measured outcomes, and effect modifiers. A narrative synthesis will describe the quantity and characteristics of available evidence, and where sufficient numbers of similar studies are available, meta-analysis will be conducted to estimate an overall mean and variance of effect.

Keywords: Dam, Discharge, Evidence synthesis, Fish biomass, Fish density, Fish richness, Flow modification, Hydropower

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Background

Maintaining the ecological characteristics of fluvial systems altered by the demands of hydroelectricity production requires the careful management of flow regime

components including magnitude, duration, frequency, timing and rate of change. Natural flow regimes have regulated both geological and biological components of natural waterbodies through time [1–3] and aquatic biota have evolved and adapted to the specific dynamics of their environment [1, 2, 4]. Alterations to flow, such as those caused by hydroelectricity production, can disrupt these natural processes and result in a variety of environmental and species responses [2]. Understanding how these alterations impact fluvial systems is important for water resource and fisheries management.

The effects of hydroelectricity production on fish living in or traveling through fluvial systems can include alterations to fish abundance and diversity (e.g., Haxton et al. [5]; Guénard et al. [6]) which may decrease or increase in response to these changes in flow (see Fig. 1 for a simple conceptual model). Studies have shown that communities differ in diversity and composition between areas that are regulated by hydropower facilities and those that are not [7, 8] and fish abundance has been found to consistently decrease in relation to alterations in flow magnitude [9, 10]. Establishment of better managed flows can have positive impacts on fish species (e.g., after establishment of minimum-flow releases, fluvial specialists increased in density compared to before-minimum conditions [11]). These studies indicate that fish responses may be dependent on the type of hydropower facility, the type of "designer" flow regime or near-natural flow regime [12], and the magnitude of alteration.

Almost half of all rivers globally are altered by river regulation or fragmentation [13], and hydropower dams are a major contributor to these alterations. With hydropower expected to increase globally and in North America as demand for green energy increases [14–16], understanding how alterations of specific flow components impact fish responses is essential. The effective management of flow regimes to provide flow characteristics that support both fish productivity and energy production in systems affected by hydroelectricity production, requires a better understanding of how fish respond to flow component alterations at hydroelectric dams, and may even require a re-evaluation of how modified river flows are designed (e.g., Soininen et al. [17]; Tonkin et al. [18]). Available evidence syntheses often focus on the effects of passage on behaviour, injury and/or mortality of fish associated with hydropower facilities [19–21], or on the alteration in abundance and diversity of fish populations associated with impoundments [22]. While reviews on ecological responses to altered flows have been done in the past [9, 23, 24] there remains a need to update our understanding of fish-flow interactions. Additionally, there is uncertainty surrounding how fish respond to alterations in specific flow components [25]. A systematic review of how flow components such

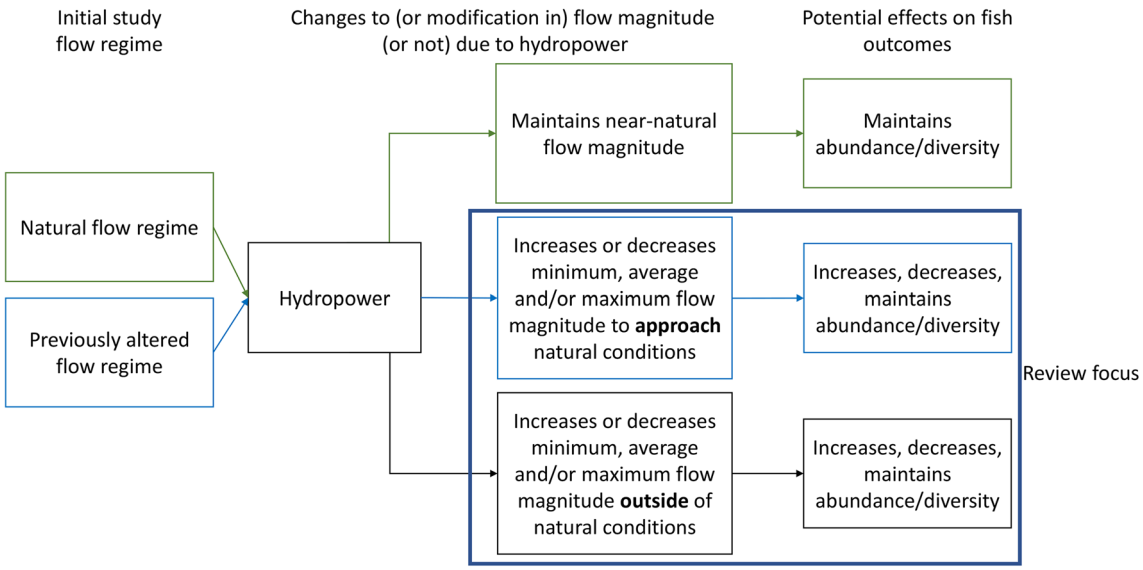

Fig. 1 Conceptual model linking changes in flow magnitude due to hydropower to potential changes in abundance and diversity of freshwater fish in flow regimes that are initially natural or previously altered by hydroelectricity production (i.e., where a change to, or modification in, the operational flow regime has occurred at an existing hydropower facility). Green pathway: maintenance of near-natural flow magnitude after hydropower production resulting in little effect on fish abundance/diversity; Blue pathway: an operational change/modification to flow magnitude at an existing hydropower facility to approach natural conditions resulting in a change (increase or decrease) or maintenance of fish abundance/diversity; Black pathway: alterations in magnitude from hydropower production from either natural or previously altered flow regimes resulting in a change (increase or decrease) or maintenance of fish abundance/diversity

as magnitude, altered by hydropower dams, affects fish abundance and diversity would add valuable information to flow management decision making.

Identification of review topic and stakeholder engagement

At the request of Canadian stakeholders [i.e., Fisheries and Oceans Canada (DFO)], a systematic map was recently conducted (Rytwinski et al. [26]) to provide a summary of the existing literature base on the impacts of flow regime changes on direct outcomes of freshwater or estuarine fish productivity. A total of 1368 relevant studies describing a variety of flow regime alterations and fish productivity responses were identified. The map focused on temperate regions and was global in scope. The map followed the Collaboration for Environmental Evidence (CEE) guidelines for systematic mapping [27], whereby they described the quantity and key characteristics of the available evidence, and identified evidence clusters and knowledge gaps, but did not synthesize results.

From the map, 11 potential subtopics were identified as areas that had sufficient coverage to allow systematic reviewing. The subtopics "the effect of alterations to flow magnitude due to hydropower production on fish abundance" and "the effect of alterations to flow magnitude due to hydropower production on fish diversity and richness" were identified as candidates for full systematic reviewing based on the presence of sufficient evidence (74 studies of abundance, 24 of biomass, and 36 of diversity) 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. Although not included in this review, the subtopic "the effects of alterations to flow magnitude due to dams with no hydroelectric facilities on fish abundance" (46 studies) was also identified as a candidate for future systematic reviewing. Canadian stakeholders acknowledged that a comparison of the relative effects of dams with and without hydroelectric facilities on fish abundance, diversity, and richness deserves future attention; however, this comparison is beyond the scope of this review.

An Advisory Team made up of stakeholders and experts including academic scientists from Canada and USA (four members), staff from DFO, specifically the Fish and Fish Habitat Protection Program (FFHPP) (one member), and Science Branch (three members), as well staff from hydropower industry (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.

Objective of the review

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 hydropower production in order to better inform decisions in water resource and fisheries management.

Primary Question

How do changes in flow magnitude due to hydroelectric power production affect fish abundance and diversity in temperate regions?

Components of the primary question

The primary study question can be broken into the study components:

Subject (population)—freshwater and estuarine fish in temperate regions.

Intervention/exposure—changes to (or manipulations of) flow magnitude due to hydroelectric production.

Comparator—no intervention or alternate levels of intervention.

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

Methods

The review will follow the CEE guidelines and standards for systematic reviews [27] and conform to ROSES reporting standards [28] (see Additional file 1).

Searching for articles

Selection of studies identified in the systematic map

Much of the evidence on which this systematic review will be based will be from the recently completed systematic map on fish productivity and flow alteration mentioned previously. In this map, a total of 1368 relevant studies were identified, of which 74 considered flow magnitude alterations due to hydroelectric power generation, and a fish abundance metric, 24 considered fish biomass metrics, and an additional 36 studies reported on flow magnitude, hydroelectric power generation and a fish diversity metric. The systematic map searched for commercially published and grey literature using six publication databases (July 2017), one search engine (July 2017) and 29 specialist websites (Feb 2017). In addition, reference sections of 297 relevant reviews and all accepted articles 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 (Feb and Nov 2017).

Search update

Search terms and language The systematic map informing this systematic review identified studies considering the impacts of alterations to any flow component on fish productivity (Rytwinksi et al. [26]). The search string used in the systematic map can be found in Additional file 2.

To identify more recently published literature on the specific topic of this systematic review, a search update will be performed using a subset of the search terms used for the systematic map (Table 1). We conducted a scoping exercise in Sept 2019 to assess original search terms from the map and alternative search terms related to this review topic (see Additional file 2). The three components of the search, population, intervention/exposure and outcome 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 were used to search exact phrases (e.g., "hydro dam" includes the exact phrase hydro dam as well as the hyphenated hydro-dam).

The search update will only cover literature published since 2017, so a limited number of articles is expected (see Additional file 2 for the number of records retrieved by scoping searches using this search strategy). 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. All bibliographic databases will be accessed using Carleton University's institutional subscriptions as outlined in Additional file 3. 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—collection of dissertations and theses from around the world, spanning from 1743 to present.
3. Science.gov—US 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.
6. AGRICOLA (Agricultural Research Database)—US 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. The first 500 hits (sorted by relevance) will be screened for appropriate fit with the review question. Customizable search strings used in the search engine will be recorded in an appendix.

Specialist websites Twenty-nine specialist organization websites were searched in the systematic map using abbreviated search terms (see Rytwinski et al. [25]). 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 websites.

Table 1 Search string that will be used to update searches from 2017 onward

Component	Search string
Population terms	TS = ((Fish*) AND ("Fresh water" OR Freshwater OR Stream$ OR Water$ OR River$ OR Fluvial OR Estuar* OR Reservoir$ OR Impoundment$ OR "Hydro electric*" OR Hydroelectric* OR "Hydro dam*" OR Hydrodam* OR "Hydro power" OR Hydropower OR "Hydro" OR Dam$)
	AND
Intervention/exposure terms	(Flow* OR Discharg*)
	AND
Outcome terms	(Productivity OR Biomass OR Abundance$ OR Densit* OR Yield$ OR "Ecological response" OR "Ecosystem response" OR "Biotic response")
	NOT
Exclusionary terms	(Mining OR "Mine site" OR Aquaculture OR "Wastewater treatment" OR Carbon)

Supplemental searches The reference sections of all accepted articles and any relevant reviews found during searching will be hand searched to evaluate articles that have not been found using the search update strategy. Only additional articles from 2017 forward 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. Stakeholders 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 of 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 criteria than the focus of this review) were identified through databases and search engines (88%), with relatively few articles identified through website searches (3%). The remaining included articles were identified from the reference sections of reviews and included articles, or through calls for evidence (9%). We therefore consider it sufficient to base the search update on the same databases and search engines as used in the systematic map (Rytwinski et al. [25]), complemented with the supplemental searches described immediately above.

Search record database

All articles found by database and search engine searches will be exported into separate Zotero databases. Once all searches are complete and references from each strategy have been compiled, individual databases will be exported into EPPI-reviewer as a single database. Duplicates will then be identified and merged. All references, regardless of their likely relevance to the systematic review, will be included in the database so that it can act as an archive. This database is a direct product of the search strategy and will not be changed during the review process. The database will therefore be useful when updating the systematic review archive in the future (current timeframe for updating is approximately every 5 years).

Article screening and study eligibility criteria

Screening process

Articles will be screened at two 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, two reviewers using a random subset of 10% of all articles or 100 abstracts (whichever is larger) will undertake consistency checks at both stages to ensure consistent and repeatable decisions are being made. At least one of the reviewers will have participated in the original screening for the systematic map and will therefore be familiar with the relevant literature and eligibility criteria. 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 $\geq 90\%$), articles will be screened by one experienced reviewer. Articles found through calls for evidence or from the reference sections of accepted or review articles will be screened at full-text but will not be included in consistency 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 and a list of studies rejected at full-text will be provided in an additional file together with 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) for which they are an author.

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 salt water). 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 and streams, that are associated with a hydroelectric dam system will be included.

Eligible intervention/exposures Articles that describe a change in, or modification to, the magnitude of flow. Magnitude can be defined as the amount of water moving past a fixed location per unit time [1]. Magnitude is therefore a measure of discharge and can refer to either relative or absolute discharge [1] and can be expressed in a variety of units. The focus of this review will be on the downstream fluvial effects of changes in flow magnitude. Articles that only evaluate the effects of changes in, or modifications to, the magnitude of flow upstream of a hydroelectric facility will be excluded. Relevant causes of a change or modification of the flow magnitude include hydroelectric facilities where water moves via gravity (i.e., impoundment or diversion/run-of-river) or by active pumping. Other types of operations will be excluded, including, but not limited to: (1) nuclear facilities; (2) dams without hydropower; (3) hydrokinetic systems (i.e., energy from waves/currents); (4) water withdrawal/diversion systems not associated with hydroelectric power production. Note, at the request of stakeholders, articles that do not specify a flow component [e.g., the study compares an unregulated stream (or section of a stream) to a regulated stream (i.e., regulated via a hydro dam)], or 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 with no intervention (e.g., upstream conditions); (2) separate but similar waterbodies with no intervention; (3) before intervention data within the same waterbody (i.e., pre-construction/modification/operation); (4) an alternative level of intervention on the same or different water body; or (5) controlled flume studies.

Eligible outcomes Studies must report measured effects that indicate the potential for a change in fish abundance or diversity. Outcomes include those related to: abundance, density, biomass or 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 Primary field-based studies including quantification of fish abundance and diversity outcomes, using Before/After (BA), Control/Impact (CI) including a gradient of intervention intensity that included a "zero-control" site (CI-gradient), Reference Conditional Approach (RCA), Normal Range (NR), Before/After/Control/Impact (BACI), or Randomized Controlled Trials (RCT; e.g., small in field manipulations) study designs will be included. Studies will be excluded if they use: (1) temporal trends that look at the relationship/correlation between fish abundance or diversity and changes to magnitude across time but without a 'true' before intervention time period; (2) spatial trends that do not include "zero-control" sites: (a) across waterbodies [e.g., survey fish abundance in 6 different streams (i.e., not all similar in morphology) and relate to flow magnitude]; or (b) within a waterbody [e.g., survey fish abundance in different sections of the same stream that differed in morphology (e.g., riffle and run) and relate to flow magnitude]; (3) > 1 after-treatment time periods but there was no change/modification to flow magnitude across time periods [i.e., repeat visits with no before-treatment data or control site; After-only (A-only)]; (4) > 1 impact sites but there was no change/modification to flow magnitude across impact sites [multiple impact sites but no control sites or before-treatment data; Impact-only (I-only)]; (5) a single point of time with no comparison to another site; or (6) a single impact site with no before-treatment data. Theoretical modeling, 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. [26]). 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.

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; meaning if a single article reported more than one experiment/observation (i.e., different designs/experimental setups), these will be regarded as separate studies. The focus of the assessment will be on the internal study validity (i.e., susceptibility to bias) and study clarity. Table 2 provides the criteria for the study validity assessment. These criteria represent the variables that we consider to be most important in influencing the internal validity of study findings, primarily focusing on the effects of selection and performance bias. This study validity assessment was reviewed by the Advisory Team to ensure that it accurately reflected the characteristics of an ideal study. External validity (study generalizability) will not be assessed; instead, generalizability will be captured during screening or otherwise noted as a comment in the critical appraisal tool.

Data on criteria in Table 2 will be extracted from each relevant study in a detailed and transparent manner, and entered in a MS-Excel worksheet. Any studies for which the answer is 'no' or 'unclear' to any of the questions will be classified as having low validity; studies that are not classified as having low validity will be classified as having medium validity if any of the questions are answered as 'partially', the remainder of studies will be classified as having high validity. The information from the assessments will be used to describe studies in the narrative synthesis and in sensitivity analyses during the quantitative synthesis (if performed). 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. No studies will be rejected based on validity assessment; however, a sensitivity analysis will be carried out to investigate the influence of study validity categories in the quantitative analysis when the evidence-base allows. Reviewers will not assess studies for validity for which they are an author.

Data coding and extraction strategy

Meta-data from studies included at full-text will be extracted by the Review Team and recorded in a MS-Excel spreadsheet that includes pre-defined coding. A draft version of the data extraction sheet is in Additional file 4. The extracted data will be used to assess the overall effect of flow magnitude alteration associated with hydroelectric power production 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), hydroelectric facility name, study design details (e.g., study dates, study design), intervention/exposure and comparator details (e.g., control site type, treatment magnitude, comparator magnitude, comparator type), 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 (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 outcome data that will be recorded includes: sample sizes, outcome means, and measures of variation (e.g., standard deviation, standard error, confidence intervals). When information is presented in tables or graphs, all information will be extracted; if it is not possible to interpret the information from graphs, the corresponding author of the article will be contacted (via email or phone) if time permits or imaging software such as WebPlotDigitizer [29] will be used. Comparisons will only be made within one figure/table but not between figures/tables. For example, if studies were done in two or more areas, but these results were presented in separate figures/tables, we will assume that a comparison cannot be made across figures/tables unless specified otherwise in the text. Where data are presented for multiple years, data from all years will be extracted. Where data are presented for multiple sites, data for all sites will also be extracted. 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

Table 2 Criteria for study validity assessment

Question/criterion	Response to question				Type of bias addressed
	Yes	Partially	No	Unclear	
1. Did the study consist of both temporal and spatial comparisons?	BACI, RCT	BA, CI, ALT-CI, CI-gradient, RCA, NR	N/A as study is not eligible for inclusion based on inclusion criteria	Lacking sufficient information to judge	Selection
2. Are experimental/observational units replicated?	≥ 2 independent experimental/observational units (i.e., the level of replication at which the intervention was administered/the exposure experienced)	There were at least two experimental/observational units but there is a lack of independence between these units (pseudoreplication)	No replication (i.e., < 2 independent experimental/observational units)	Lacking sufficient information to judge	Selection
3. Are intervention and comparator sites well-matched at site selection/study initiation?	Intervention and comparator sites are well-matched (i.e., similar physical characteristics). N/A for BA designs (i.e., intervention and comparator at the same site)	Intervention and comparator sites are moderately matched. N/A for BA designs	Intervention and comparator sites are poorly matched. N/A for BA designs	Lacking sufficient information to judge	Selection
4. Can the intervention be clearly interpreted?	It is clear that a change to flow magnitude has occurred and quantitative data on magnitude is reported	It is clear that a change to 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 within the same river)	N/A	The study compares an unregulated stream (or section of a stream) to a regulated stream (i.e., regulated via a hydro dam), or reports unspecified multiple components affecting flow (i.e., study does not report effects of components separately to isolate individual impacts of components)	Selection, performance, reporting

Table 2 (continued)

Question/criterion	Response to question				Type of bias addressed
	Yes	Partially	No	Unclear	
5. Was the study free of other potential confounders after sample selection/study initiation?	No or minimal confounding factors present, including e.g.: (1) no or minimal differences in environmental conditions between intervention and comparator sites and/or time periods (e.g., unplanned human alterations, floods, droughts, time-related trends), (2) no additional experimental manipulations of other flow regime components (e.g., flow frequency, duration) at the same time as magnitude alternations. Or if present, are accounted for appropriately in analysis	N/A	Confounding factors present that could have an impact on the outcome and these are not accounted for in analysis	Lacking sufficient information to judge	Performance
6. Did the study use different sampling/measurement method(s) between intervention and comparators?	Similar/consistent sampling/measurement methods are used between intervention and comparator sites and/or times (e.g., gear type, timing or size of sample areas)	Different/inconsistent sampling/measurement methods are used between intervention and comparator sites and/or times (e.g., gear type, timing or size of sample areas)	N/A	Lacking sufficient information to judge	Detection

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, two reviewers will extract information from 15 of the same articles 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 code book will be made where needed to ensure reviewers are extracting and interpreting data in the same manner.

Potential effect modifiers and reasons for heterogeneity

Potential reasons for heterogeneity will be identified and extracted from articles included at 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:

- Hydro dam operational regime (i.e., run of river or modified run of river, storage or peaking).
- Dam size (i.e., very low, low or high head).
- 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).

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.

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 hydropower production and the impact on fish abundance and diversity, and to identify factors that may influence the impact on fish responses 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) 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 (as Hedges' *g*) 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. 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 [30] using the *rma.mv* function in the metafor package [31].

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s13750-020-00198-5.

Additional file 1. ROSES form for systematic review protocols.

Additional file 2. Search string scoping exercise. Includes the original search string from the systematic map, results of the scoping exercise to come up with final search terms and string, and the number of records retrieved by the scoping searches.

Additional file 3. Institutional subscriptions. Details of institutional subscriptions for the databases to be used to carry out searches.

Additional file 4. Draft extraction sheet. Contains a draft version of the data extraction sheet which includes the meta-data to be extracted along with the quantitative study results, effect modifier data, and a codes sheet.

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Authors' contributions

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Not applicable.

Competing interests
The authors declare that they have no competing interests.

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