Mactaquac Aquatic Ecosystem Study Report Series 2021- 077

A FRAMEWORK FOR FUNCTIONAL FISH PASSAGE DECISION MAKING

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Correct citation for this publication:

Dolson, R., R.A. Curry, P. Harrison, and G. Yamazaki. 2021. Fish Passage Decision Making – Recommendations and a framework from a jurisdictional review. Mactaquac Aquatic Ecosystem Study Report Series 2021-077. Canadian Rivers Institute, University of New Brunswick, 79 p.

Executive Summary

This report provides recommendations and proposes a framework to support objective and consistent fish passage decision-making at large barriers in rivers. The recommendations are based on the science compiled from a broad jurisdictional review of published literature, grey literature, and discussions with fish passage experts and decision-makers. Specifically, this report summarizes the key challenges, uncertainties, and opportunities outlined in contemporary fish passage research. A series of biological questions are proposed to help decision-makers determine what species should be passed at a barrier, if any, and how many. The report advocates for the use of structured decision-making to support of a quantitative analysis of management options, one that embraces the uncertainty of unknown biological consequences and also promotes the inclusion of differing views from rightsholders and stakeholders.

The recommendations in this report integrate emerging fish passage considerations into a decision-making framework that promotes a multi-species, functional fish passage approach. This report does not advocate for specific goals related to fish passage at the Mactaquac Generating Station (MQGS). Rather, this report strives to provide a framework for making fish passage decisions at the MQGS and large barriers in general. We propose an adaptive management planning process that utilizes key biological questions to assess the outcomes of management options against defined goals and objectives using a quantitative approach.

1 Introduction

In 2014, the Canadian Rivers Institute (CRI) and New Brunswick Power (NBP) formed a partnership to evaluate the potential impacts of several renewal options proposed for the aging Mactaquac Hydropower Generating Station (MQGS). The MQGS is located on the Wolastoq / Saint John River (SJR) above the head of tide and near Fredericton, New Brunswick, Canada (Linnansaari et al. 2016). The partnership resulted in a research-based program called the Mactaquac Aquatic Ecosystem Study (MAES). In December 2016, NBP selected the "Life Achievement" renewal option, which will see the current MQGS facility refurbished to maintain its current design and in its current location (Samways et al. 2018).

The MQGS dam was completed in 1968 and resulted in a complete barrier to fish passage, as well as the formation of a large reservoir known as the Mactaquac Headpond. The headpond is roughly 97 km long and encompasses an area of 83 km^2. It is moderately deep and exhibits a lentic (lake) like ecosystem with moderate water residence time (~16.4 days from May to October; Watt 1973), seasonal thermal and dissolved oxygen stratification (Dolson-Edge et al. 2018), and the presence of lake-type plankton species (Nguyen et al. 2017). To mitigate the effects of the dam on fish passage for anadromous the Atlantic Salmon (*Salmo salar*), a fish capture facility was constructed at the MQGS in 1968. Fish passage at the MQGS is accomplished through a non-volitional trap and truck program. The trap consists of a collection gallery with six underwater entrance gates that lead to a holding pool where fish are forced into a sorting facility using a mechanical crowder. Two connected pools comprise the sorting facility and are designed to segregate Atlantic Salmon from other species. From the sorting pools, hoppers are used to lift the fish to transfer trucks (Ruggles, 1974). A fish hatchery was also built to augment Atlantic Salmon spawning in the river to offset the anticipated loss of spawning productivity due to restricted access to spawning grounds.

Retaining the existing MQGS structure, as outlined in the Life Achievement option, necessitates either the continued use of the trap and truck program or the construction of a new fish passage system to facilitate upstream movement. Downstream fish passage is currently not managed at the MQGS (i.e., fish pass downstream by moving through the turbine or spillway, somewhat volitionally).

Currently, only Atlantic Salmon (*Salmo salar*) and Gaspereau (collectively Alewife and Blueback Herring; *Alosa pseudoharengus, A. aestivalis*), are actively managed at the MQGS facility (i.e., captured and moved upstream of the dam through the trap and transfer program). The renewal of the MQGS has allowed for a discussion of what, if any, additional fish species may require passage at the MQGS in order to meet modern ecological and cultural opportunities and/or concerns (Curry et al. 2018; Samways et al. 2018, Chateauvert et al. 2018; Linnansaari et al. 2015a, 2015b).

However, the history of fish passage at large dams demonstrates that decisions regarding what species to pass, and at what proportion of the population, are notoriously difficult to make and often rely on subjective, unquantified, and narrowly defined objectives

(Katopodis, 2013; Pelicice and Agostinho, 2008; Silva et al. 2018). For example, the Canadian *Fisheries Act* (1985/2019) requires provisions for "fish" passage (Section 34) where the definition of fish includes all life stages of fish, shellfish, crustaceans, and marine mammals. However, passage has rarely been required for species that are not either commercially or recreationally important, or a species at risk (though see exceptions in Bunt et al. 2001 and Christensen, 1994). Where comprehensive watershed or fisheries management plans exist (e.g., Migratory Fish Management and Restoration Plan for the Susquehanna River Basin, Miller et al. 2010), aspirational goals and measurable objectives can guide fish passage decision-making during dam construction, relicensing, or removal (Bobrowicz et al. 2010). In the absence of such plans, fish passage decisions are often made with respect to a single barrier of interest, for a limited number of target species (Birnie-Gauvin et al. 2018; Mossop and Higgins, 2012), and often where ecological or economic values and objectives are at odds (McLaughlin et al. 2013; Pelicice and Agostinho, 2008; Pompeu et al. 2012).

This report provides recommendations to inform objective and consistent fish passage decision-making at large barriers (e.g., what species and how many individuals) such as the MQGS. The recommendations are based on the science taken from a broad jurisdictional review of the published literature including grey literature, legislation and regulations, management plans, and decision-making frameworks, as well as discussions with fish passage experts and decision-makers.

The recommendations integrate emerging fish passage research (the science of) into decision-making with a focus on a multi-species, functional fish passage approach (Birnie-Gauvin et al. 2018). This report does not advocate for specific goals related to fish passage at the MQGS. Rather, we strive to provide a framework for making fish passage decisions at the MQGS and similar large barriers on other rivers using an adaptive management planning process (e.g., Sit et al. 1998; Walters 1986). We focus on answering key biological questions and assessing the outcomes of management options for fish using a quantitative approach. The report focuses on the biological needs of fish for effective passage and does not consider important socio-economic and anthropogenic energy considerations that are entwined in a full management planning process.

For the purposes of this report, **functional fish passage** is defined using a modified version of the definition in Linnansaari et al. (2016), where functional fish passage is a solution that sustains a healthy, naturally reproducing population based on the principles that:

1) *Passage must be safe - minimal stress, injury, and mortality,*
2) *Passage must be effective - a sustainable proportion of individuals must be passed,*
3) *Passage must occur with minimal delay - fish must be able to reach their destination within necessary windows of ecological and physiological requirements; and*
4) *Passage must result in the ecological endpoint for migration/movement (e.g., spawning, rearing, emigration, overwintering, etc.) for a sustainable portion of the population.*

In developing our recommendations and framework, emphasis was placed on more recent articles and management plans given the vast changes in the field of fish passage over the last 20 years. A search of online publications and available databases was undertaken using relevant key words. We evaluated resources that included one or more of the following: 1) an evaluation of fish passage targets; 2) watershed or fisheries management plan with passage goals or objectives; 3) select license conditions for dam operation/construction that addressed fish passage; or 4) discussions with fish passage experts and practitioners regarding on-going fish passage decision-making (including legislation and regulations). An annotated bibliography of reviewed literature and reports is provided in Appendix A.

2 A Framework for Fish Passage Decision-Making

2.1 Introduction

Barriers are considered one of the major threats to the persistence of freshwater fishes in rivers around the world (Olden 2016; Barbarossa et al. 2020). An objective and consistent approach to fish passage decision-making would significantly enhance the sustainability of commercially, culturally, and intrinsically valuable fish species in a river basin. This requires engagement from all levels of government, regulators, rightsholders, scientists, and power operators, and necessitates a system wide approach to barrier and passage assessment. It is no longer acceptable to evaluate one barrier in isolation or to consider only commercially important fish species (O'Hanley et al. 2020; Duarte et al. 2021).

2.2 Fish Passage Efficiency and Management at Dams

Beginning in the 2000s, emerging research challenged the underlying assumption that all barriers can and should provide fish passage to mitigate the predicted consequences of the barrier (Jager 2006; Mallen-Cooper and Brand 2007; McLaughlin et al. 2013; Government of Ontario, 2017; Pompeu 2012; Silva et al. 2018; Sweka et al. 2013). In many cases, it has been shown that ineffective or maladaptive passage options including lack of consideration of available upstream habitat (quality and quantity) or downstream passage, can harm a population as much as a complete barrier without passage (Jager 2006; Mallen-Cooper and Brand, 2007; Silva et al. 2018; Pompeu et al. 2012). For example, upstream fish passages have been installed without considering the broader population and community impacts to target and non-target fish species due to fallback rates, rate of passage delay, predation, physiological fitness impacts, loss of individuals from productive downstream populations, and cumulative mortality (Kemp 2016; Mallen-Cooper and Brand 2007; Pelicice and Agostinho 2008; Silva et al. 2018).

Additionally, most of the research on passage efficiency has evaluated ability based on a limited number of target species and regardless of whether the ecological endpoint was achieved (O'Connor et al. 2015; Pompeu et al. 2012; Silva et al. 2018). In nearly all cases, the target species for consideration was a commercially valuable and obligatory migratory species such as salmon and little to no consideration was given to other fish species with differing body types, behaviours, movement motivations, or swimming capabilities (Birnie-Gauvin et al. 2018; Kemp 2016; Noonan et al. 2012; Pelicice and Agostinho 2008). Around the globe, salmon-centric fishways were installed for freshwater fish communities with species that don't match a salmonid life history or salmon physiological or behavioural traits; these fishways have largely been ineffective (Birnie-Gauvin et al. 2018; Noonan et al. 2012; O'Connor et la., 2015) and at worst have led to further population declines (Pelicice and Agostinho, 2008). However, when carefully planned and monitored, fish passage for target species has resulted in population persistence and increase (e.g., American Shad - Miller et al. 2010). Still, examples of successful, multi-species fish passage decision-making and management are rare (Silva et al. 2018; Birnie-Gauvin et al. 2019).

Another avenue of research that is informative for fish passage decision-making is barrier removal prioritization. This area of research has developed multiple tools and criteria to holistically assess barriers on a watershed scale and consider when, where, and why a barrier may be mitigated or removed to improve fish passage and population health (Breve et al. 2014; Zweifel, 2016). These criteria could be adapted to assess whether or not passage should be required for a specific species or guild at a new or refurbished barrier.

Depending on the jurisdiction, the regulatory environment may be a hindrance to successful fish passage management. This occurs most often where fish passes are required by legislation at new or existing facilities (e.g., upon license renewal), regardless of the likelihood of successful passage or cumulative impact to a population (Pompeu et al. 2012). In these situations, effective passage is often defined as a proportion of fishes achieving successful ascent (Pompeu et al. 2012) up an engineered structure. This narrow view of success does not consider whether the biological reason(s) for fish migration or movement can be successfully achieved (Birnie-Gauvin et al. 2018; Pompeu et al. 2012; Silva, et al. 2018).

Most publicly accessible license conditions, permits and permitting processes, management plans, and articles that discuss fish passage decision-making focus on species in commercially important fisheries and offer limited options for accommodating opposing objectives between regulators, power operators, rightsholders, and stakeholders (see Appendix A). Contemporary discussions about fish passage often include qualitative data, focus on a limited number of species, and are made in the absence of overarching management goals and objectives (e.g., Mossop and Higgins 2012). The licensing and permitting requirements of many jurisdictions restrict the scope of passage discussions to single barriers, which often eliminates meaningful discussions about cumulative impacts (Roy et al. 2018). Additionally, recent research (Birnie-Gauvin et al. 2018; Silva et al. 2018) has highlighted that where adaptive management processes are required as part of an authorization or license, post-construction and operational monitoring results are often not publicly available, and what, if any, adaptive mitigation has been required is largely unknown (for an example of an operational monitoring requirement see FERC, 1998).

However, there are a few recent examples that offer a more holistic and adaptive approach to fish passage management and decision-making. For example, under the Water Framework Directive (WFD), European Union countries have produced a large volume of articles and management guidance documents that support fish passage decision-making and management actions in member countries. The WFD requires that member countries ensure that all barriers that significantly hamper migration for diadromous species are mitigated or removed by 2027 (Breve et al. 2014). Furthermore, several jurisdictions are moving towards evaluating passage decisions within the scope of watershed or fisheries management objectives and against defined ecological criteria (Australia - O'Connor et al. 2015; Canada - Bobrowicz 2010 and FWCP 2016; Europe - Breve et la. 2014; New Zealand - Franklin et al. 2018; South America - Pelicice and Agostinho 2008 and Pompeu et al. 2012; and the USA - Miller et al. 2010 and U.S. Department of Energy 2016).

National objective setting processes can also be used to minimize the nature-energy conflict and promote improved fish passage decision-making. For example, the 'Icelandic Master Plan for Nature Protection and Energy Utilization' demonstrates how, on a national scale, energy development potential (hydro, geothermal, and wind) can be planned to minimize environmental impact and promote consensus on the conservation of nature (Gíslason, 2016). The process utilizes expert-based assessments of four categories to develop a holistic ranking of nature, societal, and energy values that incorporates uncertainty. The rankings are used to develop a national, legislatively enforced, list of catchments where development is restricted, on-hold based on insufficient information ("waiting list"), or approved (S. Skúlason, Hólar University College pers. comm. 2019). A similar process has been used in Norway since the 1980s.

O'Connor et al. (2015) provides an informative hierarchical framework for establishing performance standards to define fish passage efficiency in Australia. First, broad ecological objectives must be established (or drawn upon from existing watershed or fisheries management plans). The objectives should be clearly defined and justifiable, for example, 'to maintain fish distribution and abundance throughout the watershed'. Based on the overarching ecological objectives, site-specific or watershed specific fish passage objectives are defined, for example, 'the fishway will pass juvenile eel upstream between June and September'. Finally, the fish passage objectives are used to inform structure specific performance standards which are quantifiable and measurable, for example, 'the fishway must pass 95% of Striped Bass of a size greater than 100 mm in total length'. New Zealand has recently adopted this approach to fish passage design and monitoring (Franklin et al. 2018).

2.3 The Passage Decision Framework

Based on the above review and synthesis of contemporary research, we present a fish passage decision framework that utilizes a series of guiding biological and ecological questions to assess the ecological need for passage for species or guilds at a large barrier, e.g., to complete a life cycle (Part 1) and to assess the effect of passage on population resilience, e.g., success of life cycle completion (Part 2). Part 3 of the framework outlines a decision-making process that incorporates the information collected in Part 1 and 2. Some of the key references used to build the framework include British Columbia's "Fish Passage Decision Framework for BC Hydro Facilities" (FWCP, 2016), Bobrowicz et al. (2010), Jager (2006), Government of Ontario (2017), McLaughlin et al. (2013), O'Connor et al. (2015), Pelicice and Agostinho, (2008), Pompeu et al. (2012), Silva et al. (2018) and Sweka et al. (2014). The framework assumes that every river system requiring fish passage management will have unique characteristics related to ecology, socio-cultural values, and water resource use. Therefore, the framework is robust, accommodating variations in emphasis among its three parts.

The framework is presented as a tool for systems without existing fish and fisheries management plans. Its success requires that regulators, rightsholders, and stakeholders first establish aspirational goals for the system to guide the passage decision-making process. Following the development of goals, participants must develop measurable targets to evaluate uncertainties and the likelihood of success of different passage scenarios. Success of passage is assessed as achieving functional passage based on monitoring data (see for examples, Bobrowicz et al. 2010; Franklin et al. 2018; McLaughlin et al. 2013; O'Connor et al. 2015; Pelicice and Agostinho, 2008; Silva et al. 2018; and Wisconsin Department of Natural Resources, 2017).

This report and its framework advocate for the use of a structured and quantifiable decision-making process that can appropriately weigh different fish passage management options that arise from Parts 1and 2 as key inputs for Part 3. Each system will be different ecologically with varied states of knowledge and data availability, and in different states of management which entails that the process will be flexible to ensure the identification and quantification of uncertainty associated with any metric used in the decision-making process. Ultimately, all successful fish passage decision-making will incorporate a multi-species, ecosystem focus that is participatory and transparent, and that embraces uncertainty.

2.4 The Framework Structure

Part 1– What Species Require Passage

The initial step in the framework will guide decision-maker's evaluation of what species require passage at a barrier. A system may have a complex fish community or lack enough knowledge of extant species such that a fish guild approach may be a more appropriate classification for passage needs (Welcomme et al. 2006; Wegschieder et al. 2020). This flexibility is an example of the adaptive approach required of the framework and for fish passage management in general. The approach for the Part 1 assessment is to (1) identify species or guilds of importance for a barrier or series of barriers based on watershed, conservation, or fisheries management goals and objectives, and (2) determining the ecological consequence of providing passage for the identified species/guilds.

<u>Guiding Questions</u>:

a) What are the species and species-specific priorities in the system?
   - What are the species movement/migratory needs as they relate to the barrier (s) in a system (asked for each of the species of importance)?
   - Does the barrier block the migration or movements of the species?
   - Is migration or movement across the barrier necessary for the species to carry out its life cycle?

b) Is the population(s) viable and naturally self-sustaining with the barrier in place, i.e., upstream, downstream, or both?

c) Will passage ensure or hinder sustaining a viable population (upstream, downstream, or both)?
   - Does habitat of a necessary quality/quantity exist upstream/downstream of the barrier?
   - If additional barriers exist, what is the cumulative effect on quality habitat and availability?
   - Is the existence of a headpond(s) or reservoir(s) an ecological barrier or trap for a species passing upstream or returning downstream and what rate of mortality is associated with each headpond?
   - Are there viable solutions for effective, functional fish passage up- and downstream for all life stages of the species?
     - What are the negative impacts of passage (e.g., rate of direct and indirect mortality, severity and frequency of non-lethal injury, rate of delayed mortality, and cumulative mortality rates across multiple barrier systems)?
     - Can these impacts be mitigated? How and at what is the cost? Mitigation implies specific design criteria and performance standards.

d) If species knowledge is limited or many species exist in a system, then passage questions could be applied to fish guilds defined by behavior in association with barriers in a river, e.g., benthivores approaching along the bottom (e.g., sturgeons), rheophilic classes (e.g., surface schooling river herring), etc.
e) What are the population and community consequences of either providing or restricting passage, e.g., impact on unionid mussel host-fish species, invasive species (including pathogens)?

Other biological or ecological questions may be relevant to a particular watershed or barrier if species at risk or other species of concern are present, i.e., the importance, or weight, assigned to each question above will depend on the particular watershed and species needs. The answers to the Part 1 questions can then be assembled as a decision matrix based on likelihood of successful up- and downstream passage for each species or guild at each barrier (based on the barrier and headpond) and cumulatively, as well as the broader ecological consequences of successful passage.

Part 2 – What Proportion of a Population Should be Passed

The preferred outcome at a barrier is 100% passage success. However, it is understood that fish passage, even if efficient and effective, does not guarantee the existence of a naturally self-sustaining population nor a healthy population. In situations where passage is deemed to be required (Part 1) and the bi-directional passage can be estimated, decisions regarding how many individual fish to pass will also be necessary. These decisions will be based on species specific needs, i.e., accessing specific habitats to complete a life cycle (e.g., diadromous species) and population-scale goals (i.e., self-sustaining and healthy).

<u>Guiding Questions for Each Species Identified in Part 1</u>:

a) What is the estimated population size for the species up and downstream of the barrier?
b) What is the estimated mortality rate at the barrier and cumulative mortality rate for each species across all barriers in the system?
c) Where are suitable habitats for the species located in the watershed and how much habitat (for each life history stage) exists upstream of the barrier?
    - What is the spatial partitioning of these habitats, including across the system in multiple barrier systems?
d) What is the capacity of the fish pass structure (i.e., daily)?
e) What is the species migration/movement period?
f) What is the estimated productivity (e.g., egg per recruit) of all available habitats up and downstream of the barrier?
g) How will productivity change with fish passage at each barrier?

h) What is the estimated mortality due to other factors (e.g., commercial and recreational harvests)?
i) What is the cumulative mortality rate at the barrier considering passage mortality and other mortality factors (identified in "h" above")?
j) Is there a need to pass a portion of the population to meet social or cultural goals?
    - Is there a social or cultural harvest quota? If so, how many individuals of each life history stage will be harvested?
k) If species are collectively managed as guilds, what is the cumulative mortality across all species?
    - Are there species in the guild most at risk of direct and indirect effects associated with passage?
    - Can one species best represent the guild and therefore become of the target for passage decisions?
l) Does a population model with variability estimates for each passage scenario exist? If not, then a model of some form will have to be created.
m) Will provision of upstream passage impact a self-sustaining population downstream of the barrier?
    - Can this be quantified (a model exists or must be built)?

The answers to the Part 2 questions can then be assembled as a decision matrix based on the best estimates of the biological outcomes of passage for each species or guild at each barrier (based on the barrier and headpond) and cumulatively. Collectively, Parts 1 and 2 should provide the best available science knowledge to begin the structured decision making for designing a fish passage plan (Part 3).

Part 3 – Structured Decision-Making

Answering the questions in Part 1 and 2 will not generate an effective fish passage solution for a system because: (1) it is rare that sufficient historical and contemporary data is available to fully answer all the questions; (2) there is always uncertainty in estimates; and (3) there will always be competing management objectives beyond fish passage for the system. To assist in evaluating different management options, our framework advocates for the use of structured decision-making (SDM; see introductions by Peterman and Peters 1998, Irwin et al. 2011). SDM is a strategic and adaptive process that can assist decision-makers in evaluating the consequences of management scenarios in the presence of uncertainty and competing objectives or values.

SDM has been used successfully in fisheries science and management to aid in complex decisions such as defining fisheries allocations (Bernstein and Iudicello, 2002; Varkey et al. 2016), and to assess alternative management options related to fish passage (Mossop and Higgins, 2012; McLaughlin et al. 2013). There are various approaches and tools used in

SDM, but the general process consists of engaging rightsholders and stakeholders (participatory approach), defining and evaluating management options and objectives, and using a modeling approach to incorporate uncertainty and predict the outcome of different management options on the stated objectives (e.g., Peterman and Peters 1998, McLaughlin et al. 2013). SDM analyses tools are numerous and include Bayesian belief network analysis, decision analysis, and real-options analysis; these will vary among practitioners. The structure and process should follow these basic steps (after McLaughlin 2013 and Peterman and Peters 1998):

1) Define the system wide, fish management objectives/targets,
2) Define passage options for each species/guild (based on Part 1 and 2),
3) Identify and estimate uncertainty with each option (based on Part 1 and 2),
4) Model the outcomes of options,
5) Build a decision-tree or decision-table based on model output,
6) Weigh and rank the management options based on the decision tree/table,
7) Perform a sensitivity analysis for the decision tree/table (i.e., which parameters are driving the decision outcomes).

2.5 Post-Framework Decision-Making

The above framework will not create a stand-alone solution for a river system. The framework focuses on the biologically relevant information required to set the decision-making stage. There will most probably be non-biological goals for species and populations, as well as the river's provisioning of goods and services, i.e., goals that are socio-economic and cultural. It will be the framework's outputs of options and their predicted outcomes from which managers can take forward in their broader, river-wide decision-making process.

3 Conclusions

This report summarizes the science related to fish passage along with the uncertainties and challenges facing management at barriers in rivers. In cases where successful fish passage management has occurred, it has done so where watershed-wide, conservation, or fish management goals and objectives are available to guide fish passage decisions. The guiding questions provided in Part 1 and 2 of the framework aim to help decision-makers understand when passage is appropriate and necessary for a species/guild, and at what level. Part 3 advocates for a quantitative analysis of the passage options that embraces the uncertainty of unknown biological consequences and promotes the inclusion of differing views from rightsholders and stakeholders through a structure decision-making process. A key caveat is that each river system and each barrier will need for a "case-by-case" approach. Together, Parts 1, 2, and 3 form a comprehensive and science-based framework to support fish passage planning, decision-making, and adaptive management.

4 Acknowledgements

This report was improved by discussion with fish passage experts from across the globe. Without their insight, contacts, and recommended readings this report would not have been possible. Experts from government, academia, consulting, and the not-for-profit sectors who kindly provided their time and expertise and are listed below. Special thanks to the late Prof. David Noakes of Oregon State University for putting the author in touch with, seemingly, everyone.

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6 Appendix A

An annotated summary of the articles and publications reviewed in this report. The list is organized in alphabetical order by jurisdiction and by author.

Author	Year	Title	Jurisdiction	Source	Species Focus	Decision Tool (Y/N)	Cumulative Effects? (Y/N)	Passage Target (Y/N)	Summary
Mallen-Cooper, M., and Brand, D., A.	2007	Non-salmonids in a salmonid fishway" what do 50 years of data tell us about past and future fish passage?	Australia	Fisheries Management and Ecology. 14: 319-332	Full community	N	N	NA	*Fishways traditionally built in the Murry River were designed to meet the swimming capabilities of salmonids and not the native fish species or life stages of the most frequently encountered a species t dams in the River. These traditional passage structures (pool-type design with gradients of 1:9) were found to be ineffective for native species with less than 1% of the abundant species being able to navigate the fish pass. *Successful fish passage in the Murry River has now moved to integrating the needs of a potamodromous fish community where upstream passage is effective for multiple species and life stages. Fish pass gradients of 1:32 with maximum water velocity of 1.4 m/s are now utilized to facilitate the passage of small bodied fish species. *In this publication, fish pass efficiency is measured as the ability of fish to enter and ascend the pass and does not assess efficiency as a relative measure of success based on the number of individuals arriving at the pass versus those that ascended. * Fish capture records from the fish pass were assessed over a 47-year period and noted a 59% reduction in the proportion of native fish captured.
O'Connor, J., Mallen-Cooper, M. and Stuart, I.	2015	Performance, operation and maintenance guidelines for fishways and fish passage works.	Australia	Arthur Rylah Institute for Environmental Research Technical Report No. 262 Heidelberg, Victoria.	NA	N	NA	NA	* This report is a grey literature publication of the State government of Victoria in Australia, and it provides insight on fish passage objective setting and how to develop biological performance standards, as well as guidance for fishway maintenance. * The report summarizes key biological characteristics that should be addressed in order to develop ecological fish passage objectives such as the historical, present and expected range of a species or guild considering passage options. * Following the development of ecological passage objectives, the authors argue that performance standards are needed to define the operational targets for the fishway (e.g., reduction of passage delay, proportional passage of specific life stages at a given flow rate). These performance standards

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									can be used as targets to assess if the ecological passage objectives have been met. *Performance standards are grouped into biological, and physical and hydrology performance standards. * The authors note that it is difficult to define the proportional number of individuals of a species (and life stage) that require passage to ensure a sustainable population and argue that to estimate this value the ecology of the species (e.g., fecundity), the species migration ecology (e.g., life stage of migration,) and the status of the species (e.g., endangered or special concern) must be known. *Several relevant examples on from the Murry River are given to highlight how objectives, performance standards, and maintenance guidance can improve fishway design and effectiveness in a multi-species, non-salmonid context.
B.C. Ministry of Forests, Lands and Natural Resource Operations, B.C. Ministry of Environment, and Fisheries and Oceans Canada	2012	Fish-Stream Crossing Guidebook: Revised Edition	Canada - BC	Government of BC	N/A	Y	N	NA	* The natural resources and environment departments of the Government of British Columbia, along with the federal Department of Fisheries and Oceans, developed a guidebook to inform fish passage requirements and mitigation options for stream crossings. * This guidebook focuses on assessment techniques to identify and quantify "critical, important, or marginal" habitats. Critical habitats are restricted to those fishes supporting a commercial, recreational, or aboriginal (CRA) fishery or a species at risk (SAR), or if the habitat is rare, sensitive, or necessary for breeding. Important habitat is habitat that is used for feeding, migration, and growth, whereas marginal habitat is that which has low fish productivity. * The guidebook suggests indicators of critical and important habitat that are based on factors most often attributed to salmonids. Marginal habitat is associated with habitat that is not suitable to salmonid rearing or persistence. * The guidebook provides a decision framework for what type of stream crossing structure is required based on the stream segment gradient and habitat classification. Cumulative impacts of stream crossings is not considered.

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Borick-Cunningham, G	2018	Alouette Watershed Sockeye-Fish passage feasibility project year 1	Canada - BC	Fish and Wildlife Compensation Program	Sockeye	N	N	N	*Through BC Hydro's Fish and Wildlife Compensation Program, the Alouette dam was identified for possible fish passage mitigation. Several technical feasibility studies were carried out between 2004 and 2017 to assess the feasibility of restoring a self-sustaining Sockeye Salmon population to Alouette Lake. * Management and restoration goals were drawn from the Alouette Watershed Coastal Action Plan and the Alouette Salmonid Action Plan. * The purpose of this synthesis was to assess the feasibility of successful passage for Sockeye at the Alouette dam, following requirements set out in BC Hydro's Fish Passage Decision Framework. Specifically, the report outlines tasks undertaken in year 1 of an 11 plan to address uncertainty regarding population viability and passage for Sockeye around the Alouette dam. * Four tasks are summarized in this report: 1) CSAS review of Sockeye Response Model and Alouette Program, 2) Alouette Reservoir Sockeye spawning behaviour and habitat study, 3) Alouette adult Sockeye enumeration, and 4) Evaluation of the migrations success of Sockeye from the Alouette Reservoir.
DFO	2014	Technical Review of the Effects of the Site C Clean Energy Project on Fish and Fish Habitat of the Peace River, British Columbia.	Canada - BC	Canadian Science Advisory Secretariat Science Response 2014/11	Peace River fish - salmonids	NA	NA	NA	*This Canadian Science Advisory Secretariat report is a DFO science review of the proponent's (British Columbia Hydro and Power Authority) assessment of the effects of the large hydropower station, Site C, on the fish and fish habitat of the Peace River. The Peace River is an important migration corridor that is necessary for certain species to complete their life cycle. * Site C is large, run of river hydroelectric project that will result in a 60 m tall dam and an 83 km long reservoir. Site C will be the most downstream dam in a series of dams on the Peace River. * BC Hydro has proposed a series of mitigation actions to offset the negative effects of the dam on fish and fish habitat including building additional habitat features, fish habitat compensation using the "like for like" model, riparian planting, providing upstream passage to select species using a trap and transfer program, as well as operational actions to minimize entrainment, sedimentation, fish stranding, and excess total dissolved gas.

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									Effectiveness monitoring of mitigation actions and monitoring of effects on fish and fish habitat are also proposed. *DFO scientists reviewed BC Hydro's assessment of the effects of the Site C dam on fish and fish habitat in the Peace river to determine if the proponent's assessment: accurately characterizes the area of impact and likely effects to fish and fish habitat in the reservoir as well as up and downstream, that conclusions regarding aquatic productivity following construction are valid, and that the proponent has drawn valid conclusions regarding residual and cumulative effects on fish and fish habitat. * The Proponent relied on modeling results (CE-QUAL-W2) to make predictions regarding the post dam water quality and primary production in the Site C reservoir. Anticipated changes to the fish community were also modelled using a species-specific biomass model (ECOPATH). The CSAS report states that the authors were concerned that productivity models were not accurate enough to make valid predictions about reservoir production. * The report outlines in detail the contradictions and uncertainty associated with the proponent's estimates of fish productivity in the reservoir, and downstream, following dam construction and questions the viability of the trap and haul program for species such as Artic Grayling. The authors also recommend an adaptive management approach be pursued with regard to fish passage in order to ensure Bull Trout persist during and following construction of Site C and its reservoir. This recommendation arises from concerns regarding the assumptions used in the productivity model that suggest the Bull Trout population will persist, and may even be enhanced, through successful upstream passage mitigation * Ultimately, the authors conclude "...some of the Proponent's conclusions regarding effects appear at odds with the information base; alternative interpretations are provided in this report."
E.M. Plate, M.A. Mathews and R.C.	2014	Technical Feasibility and recommendations for Alouette Lake	Canada - BC	http://a100.gov.bc.ca/appsdata/acat/documents/r49	Sockeye	N	Y	NA	* Plate et al. synthesize over 10 years of studies in order to provide management options in support of a self-sustaining population of Sockeye Salmon in Alouette Lake above the Alouette Dam in British

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Bocking LGL Limited		Sockeye Salmon re-establishment above the Alouette Dam		028/13.ALU.02_1443026016059_3025327969.pdf					Columbia, Canada. * The report provides background information on the Alouette dam and the subsequent decline of Sockeye Salmon in the river and persistence of Kokanee in the Alouette Lake. The contemporary outmigration of smolts from the Lake was found to be low, as was adult escapement. Returning adults are passed upstream through a trap and truck program. * The authors outline that given low adult escapement and low rate of smolt emigration, numbers of returning fish must be enhanced prior to the development of a fish passage proposal (e.g., development of a fish ladder). * To address low abundance in the near-term hatchery intervention is presented as a viable option. * The authors call for clear and realistic management objectives to be set to guide management decision-making, and prioritizing actions. * In an appendix report "Alouette Watershed Salmonid Action Plan - Final Draft, 2011" specific species management targets are identified based on an analysis of historical abundance of salmon in the river system. Such targets are useful to inform decision-making and establishing fish passage targets to meet species management targets.
Fish and Wildlife Compensation Program	2014	Peace Basin Reservoir Action Plan	Canada - BC	BC Hydro		Y	N	N	* Due to impacts from the barriers on the Peace River in British Columbia, the Fish and Wildlife Compensation Program of BC Hydro developed a restoration plan for the Peace River (prior to Site C development). *This Plan is centered on research, habitat compensation, and species revival. * The Plan does not advocate for installing or changing current fish passage mitigation due to reservoir health limitations.
Fish Passage Technical Working Group	2014	Fish Passage Strategic Approach: Protocol for Prioritizing Sites for Fish Passage Remediation	Canada - BC	Government of BC	N/A	Y	Y	NA	* A strategic document to guide fish passage remediation at road crossings in British Columbia. Guiding principles are based on a holistic understanding of the impact to fish passage on a watershed scale. * The document outlines a "Fish Passage Strategic Approach Protocol" that encompasses four phases:

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									1) Fish passage assessment and identification of priority crossings in "high fish value" watersheds, 2) Confirmation of habitat (quality and quantity) to be gained by remediation of a barrier, 3) Design and consultation, 4) Remediation work * Fish passage assessment studies are prioritized based on the presence of Species at Risk, or important salmon populations, if an assessment hasn't been completed previously, or if the watershed is designated as a fisheries sensitive watershed. *Guidance is provided to determine when remediation should **not** be pursued, such as: if upstream habitat were not fish bearing, downstream barriers would require remediation for full benefits to be realized, the barrier is below a natural barrier, or if the barrier is segregating non-native and native fish.
Mattison, J., Nowlan, L., Lebel, M., Orr, C.	2014	Water for Power, Water for Nature: The Story of BC Hydro's Water Use Planning Program.	Canada - BC	WWF-Canada	NA	N	N	N	* This document summarizes the Water Use Planning process (WUP) undertaken by BC Hydro beginning in the late 1990s. The purpose of the document was to share the lessons learned through the WUP process. *The WUP process was described as a collaborative, multistakeholder approach to water governance that aimed to balance competing water uses and electrical power needs. The impetus for the WUP process was a federal charge of destruction of fish habitat under the Fisheries Act against BC Hydro in 1991, and due to the fact that most BC Hydro dams were built prior to the HADD provision of the Fisheries Act (1977) and the structures were operating without authorization. * The WUP process was to develop a set of specified and measurable operational limits for a facility that met multiple objectives concerning fisheries management objectives and power operation targets. *Fish passage considerations were outside of the scope of the WUP process, but water spill targets to maintain habitat and downstream smolt passage were occasionally addressed in specific plans. Most plans incorporated facility objectives for minimum flows to maintain downstream habitat and allow for sufficient flow to support upstream migration.

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Mossop, B., and Higgins, P.	2012	Site C Clean Energy Project: Volume 2 Appendix Q1. Technical Report: Fish Passage Management Plan	Canada - BC	BC Hydro	Bull Trout * Some consideration for small fish species	Y	N	N	* This document incorporates several appendices including a consultant's report on fish passage alternatives assessment procured for BC Hydro in support of Site C approval process. *The overall fish passage management plan used a structured approach to assess fish passage management options according to risk, feasibility, biological benefits, and cost. The plan ultimately recommends four components: upstream passage through a trap and haul program where Bull Trout is the primary target, downstream mitigation options that center on good operational maintenance (but no dedicated bypass or other structure), periodic translocation of small fish species with a demonstrated genetic need for population connectivity, and monitoring and adaptive management. A technical steering committee is proposed to oversee monitoring and management actions. *The overall fish passage objectives at Site C are summarized as: provide safe upstream movement, minimize injury during passage downstream through the dam, and manage the loss of upstream productive fisheries capacity. * A valued ecosystem component (VEC) analysis of fish and fish habitat identified Bull Trout as a priority species for passage consideration. The trap and haul facility will be designed to meet Bull Trout needs but may also accommodate Arctic Grayling, Mountain Whitefish, Rainbow Trout, and other large bodied fish. *No alternative management options are identified if post-construction monitoring reveals that the trap and haul facility or downstream passage are not meeting VEC objectives. Appendix Q2 - fish passage alternatives assessment * The passage alternatives assessed focused on determining the biological benefit for select species based on predictions of habitat status following the construction of the dam. * The authors suggest that results from a modelling exercise demonstrate that fish passage mitigation is not expected to be biologically necessary to maintain existing population level conservation values for evaluated fish species. The authors also note that Bull Trout may benefit from upstream

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									passage mitigation resulting in benefit to conservation performance measures. * Passage is not recommended for Arctic Grayling based on anticipated impacts from the reservoir and unknown benefit to adjacent river populations. *The report does not propose or promote safe downstream passage options and fish will be required to pass downstream via turbines and the spillway. Downstream passage survival through the turbines is reported as 90% for small fish (<100 mm FL), and >60% for large fish (750 mm FL). * A structured decision-making workshop was held to evaluate alternatives for passage with select federal and provincial regulators and experts. It does not appear that rightsholders or stakeholders were engaged in this process. The process evaluated the expected biological implications of each technical alternative to determine the biological effectiveness of the option. This SDM process did not include evaluation of uncertainty of alternatives. *The authors note that the SDM process was complicated by the lack of Provincial fisheries management objectives for the Peace River at the time of the workshops and that the alternatives assessment would likely need to be revisited when such objectives become available.
unnamed	2016	Fish Passage Decision Framework for BC Hydro Facilities	Canada - BC	Fish, Wildlife and Hydro Policy Committee	Migratory fish stock	Y	Y	NA	*Purpose of document is to establish a process to determine how BC Hydro addresses fish passage issues at hydro facilities. * The rationale for improving fish passage as part BC Hydro's Fish and Wildlife Compensation Program (FWCP) is to improve the productivity of affected watersheds through the re-establishment of selected species of fish to the portions of the watershed they historically utilized. * The first assessment question in the framework automatically limits species considered for passage mitigation. Proponents for passage must first demonstrate that initial construction blocked passage for a migratory fish stock. Additionally, passage must be identified as a priority action in a Watershed Action or species action plans, or else further evaluation is required by the proponent before continuing in the decision-making process. * Feasibility studies are used to assess the need for,

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									and effectiveness of, viable mitigation options and must include information on the following topics: "1) Target species are available in the watershed in sufficient numbers to support rebuilding a sustainable population. If the target species is not available and a donor stock transplant is proposed, a thorough risk assessment related to suitability of the donor stock and impact on the donor stock must be undertaken; 2) Potential genetic, ecological and disease impacts to native species; 3) Existence of high quality spawning and rearing habitat below the dam; 4) Other physical impediments, such as other adult migration barriers below the dam, or juvenile passage issues at the facility, or different flow regimes that may limit the potential for restoration goals to be achieved; 5) Sufficient spawning and rearing habitat above the barrier to support the target fish population numbers established in the Watershed Action Plan, or the known potential to restore sufficient habitat, and 6) An assessment of the biologic benefits of a fish passage plan, as well as a summary of the risks of biologic impact and regulatory requirements." * A FWCP review committee determines if the feasibility study was sufficient and if passage is environmentally feasible and can address uncertainty and reach restoration goal: can be based on literature, or modelling or direct data collection. * Proponents prepare feasibility studies and develop business case that addresses questions of uncertainty and demonstrates benefit to review board that then must sponsor for BC Hydro. If sponsored, BC Hydro proceeds with business case development.
Christensen, B.	1994	Passage of North Temperate Fish through the Cowan Dam denil fishway	Canada	University of Manitoba	Pike, Walley, Sucker, Cisco, Whitefish	N	N	N	* Thesis evaluated use of denil fish way by several warm and cold-water species. Pike had the lowest ascension rates of the fishway. All other species used the fish way, but timing was not always related to spawning windows. Additionally, fish appeared to leave the reservoir and continue upstream although they originated from a downstream lake (~200 rkm). *Fish observed to return to downstream lake in

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									winter when upstream rivers become anoxic. *No discussion of downstream passage efficiency
McLaughlin, R.	2013a	Decision Tools in Support of Fish Passage	Canada	3rd NSERC HydroNet Annual Symposium	NA	Y	N	N	*Advocate for structured decision making to support fish passage decisions *New decision models are needed as society shifts from single species, command-control systems to ones based on multi-species and ecosystem focus, with a want for participatory management and decision making in an open and transparent environment that embraces uncertainty * Tools that can support structured decision making include: decision or real options analyses, utility functions, Bayesian belief networks, simulations, and information valuation. * Steps in a Decision Analysis process - 1) specify management objectives, 2) specify options, 3) identify uncertainties, 4) assign probabilities to uncertainties, 5) simulations linking 1-4, 6) create decision tree, 7) rank management options, and 8) sensitivity analyses
Olagunju, A., O., and Gunn, J., A., E	2015	Selection of valued ecosystem components in cumulative effects assessment: lessons from Canadian road construction projects	Canada	Impact Assessment and Project Appraisal. 33 (3):	NA	NA	NA	NA	* Under Canadian environmental assessment legislation, valued ecosystem components (VEC's) are used in the cumulative effects assessment (CEA) process to assess impact, inform mitigation requirements, and outline necessary monitoring. This paper attempts to discern how VECs are selected during the CEA process, because no formalized or public policy on the process was available at the time of publishing. * The authors examined 11 road infrastructure projects in Canada that occurred between 1995 and 2011 to discern how VECs were chosen for the CEA analysis. *The authors found a lack of guidance for VEC selection across projects and that VECs chosen were often insensitive to linear road construction project impacts.
Bobrowicz, S.M., D. Nuttall, N. Wiens, K. McNaughton and M. Proulx	2010	Black Bay & Black Sturgeon River Native Fisheries Rehabilitation — Fisheries Management Zone 9 Advisory Council	Canada - Ontario	Ministry of Natural Resources. Ontario.	Walleye	Y	Y	N	* As part of Ontario's Ecological Framework for Fisheries Management, the provincial waterbodies and waterways were divided into ecological zones. Each zone would support a Fisheries Management Advisory Council that would review scientific information and provide value-based recommendations for fisheries management. The Advisory Council in Zone 9 was asked to review

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		Recommendations and Rationale.							options related to the Camp 43 dam on the Black Sturgeon River. * This article summarizes the recommendations of Fisheries Management Zone 9 (FMZ 9) advisory council with regards to native fish rehabilitation in Black Bay and Black Sturgeon River in Northwester Ontario. * The most downstream dam (camp 43 dam) on the Black River (a tributary of Lake Superior) blocks access to 80% of the upper watershed. This barrier prevents spawning movements of a provincially listed species at risk, Lake Sturgeon, as well as migratory movement of the commercially and recreationally important Walleye. The dam is also a barrier to the invasive Sea Lamprey and prevents lamprey from accessing spawning habitat. * The Zone Council reviewed dam options with respect to two primary goals: "1) Native species rehabilitation in Black Bay and the Black Sturgeon River, and (2) Effective and cost-efficient sea lamprey control in the Black Sturgeon watershed. " *The Zone Council also ensured that their recommendations were aligned with the Fish Community Objectives for Lake Superior which aim to restore and maintain self-sustaining populations of native fish in Lake Superior. *Following the review of all available information, the Zone Council provided a preferred and alternative option to the Ontario Ministry of Natural Resources based on subjective ranking of a number of criteria. For each dam option, Council members ranked (from 1-low, to 5-high) the anticipated benefit for each criterion. *The criteria the Council considered included: the benefits to walleye, sturgeon or brook trout populations; the long term social/cultural benefit; recreational and economic benefits; ramifications of financial costs associated with implementation of each specific course of action; and the potential consequences of increased populations of less desirable species such as lamprey or other invasive species that currently or could eventually inhabit Lake Superior. The level of positive response of the walleye, sturgeon and brook trout populations had to be weighed against associated costs and environmental risks for each option which included

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									dam demolition or refurbishment costs, the cost to staff a new fishway, and increase cost for sea lamprey control. * A trap and sort program option was considered, but the Council cautioned that the public must understand: a" trap and sort system may not be sustainable over the long term and that this option does not support the establishment of self-sustaining fish populations".
Furlong, P., Foster, R.F., Colby, P.J. and Friday, M	2006	Black Sturgeon River dam: a barrier to the rehabilitation of Black Bay walleye	Canada - Ontario	OMNR Upper Great Lakes Management Unit, Lake Superior. Technical Report 06-03, 30.	Walleye	Y	N	N	* This report summarizes the results of a number of projects designed to identify impediments to the recovery of the Walleye population in Black Bay, Lake Superior. The report attempts to address uncertainty regarding the role of the river's most downstream dam on Walleye recovery. * The objective of the report is to provide scientific information to support decision making regarding removal or mitigation of Black Sturgeon dam (Camp 43 dam); that is the report attempts to answer the question, if Camp 43 is removed are the anticipated benefits to Walleye recovery viable? * Report documents adequate quantity of spawning habitat downstream of dam, but notes that it may not be of sufficient quality. It remains unknown if dam removal would promote sufficient reproduction upstream based on habitat quantity alone. However, based on Walleye spawning site fidelity and congregation below dam, the report suggests that passage would improve spawning success due to 5-fold increase in access to suitable habitat upstream. * The report also suggests additional benefits of dam removal include increased access to habitat for Brook Lamprey, Lake Sturgeon, and Brook Trout, secession of dam operating costs, and restoration of genetic connectivity. However, large and uncertain negative consequences are also likely including the increased cost of Sea Lamprey control and movement of other non-natives such as Rainbow Trout into the river.
Government of Ontario	2017	Draft - Government Response Statement to the Recovery Strategy for the American Eel in Ontario	Canada - Ontario	Government of Ontario	American Eel	Y	Y	Quantitative	*This draft (subject to change) document outlines Ontario's formal commitments and priorities for the protection and recovery of American Eel in Ontario * Following consultation with stakeholders and the general public, and considering the Recovery

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									Strategy for American Eel, Ontario's to protect and recovery American Eel is: to increase proportion of eel that migrate out of Ontario within 25 years by reducing threats in Ontario and other jurisdictions, and by prioritizing recovery actions to enable sustainable cultural experiences and practices including maintaining/returning eels to previous range, where feasible. * In Ontario, one of the largest threats to American Eel is the lack of safe downstream passage at hydroelectric facilities. This document provides rational for why all barriers will not be considered for upstream passage mitigation, specifically the document states that, "To ensure that actions are in the best interest of the species, decisions about where to facilitate upstream passage of eels must take into account the amount of habitat required by the species, and the risk that eels may be killed when migrating back downstream." * Actions prioritized as government priorities focus on understanding and limited the cumulative impact of downstream mortality and to determine the threshold mortality at which upstream passage is no longer a benefit to the species. * Identified actions that will be either government led or supported to increase eel survival include: "develop river specific cumulative mortality estimates and downstream survival thresholds; evaluate existing data to determine recruitment and escapement and develop new indices where necessary; develop and monitor targets for escapement; develop a passage implementation plan identifying priority barriers for passage; undertake actions identified in implementation plan; update and review hydro best management practices for minimizing mortality; and, develop standardized practices for monitoring survival" * The passage implementation plan will be developed collaboratively with industry and stakeholders and be based on "site specific and cumulative mortality estimates, river wide survival thresholds, effectiveness of proposed passage options, and considering socio-economic factors".
Katopodis, C	2013	Fish Passage considerations for developing small	Canada - Ontario	Katopodis Ecohydraulics Inc	NA	NA	NA	NA	*This report summarized the legislative and regulatory context of fish passage decision making and opportunities in Ontario based on the Fisheries

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		hydroelectric sites and improving existing water control structures in Ontario							Act of pre-2015 (that is, before HADD provisions were removed). * The report also outlines how (in pre 2015 cases) Fisheries and Ocean's Canada (DFO) utilized a risk management framework to characterize project impacts on fish movements and to evaluate the effectiveness of fish passage mitigation options. The author notes fish passage objectives were often used to guide decision-making regarding mitigation options, because HADD provisions of the pre-2015 Fisheries Act required no net loss of productive capacity. * The author notes that DFO is responsible for establishing fish passage objectives. When local fisheries or watershed management plans exist, they are considered the best source of local information to guide fish passage decision making based on local objectives and to identify target species. * A jurisdictional review of fish passage decision-making processes is provided encompassing Alberta, British Columbia and Europe. *The author notes that "the decision-making process on whether fish passage is required or not for a specific project or what passage systems are needed to be effective is frequently lacking."
McLaughlin, R. L., Smyth, E. R. B., Castro-Santos, T., Jones, M. L., Koops, M. A., Pratt, T. C., and Vélez-Espino, L.A.	2013b	Unintended consequences and trade-offs of fish passage	Canada - Ontario	Fish and Fisheries: 14, 580–604	N	Y	NA	NA	* Authors of this report highlight the unintended consequences of providing fish passage to fishes at barriers considering both cases of upstream passage mitigation and dam removal. The article highlights that the consequences of providing passage necessitate a trade-off between potential positive and negative ecosystem impact that are often overlooked in fish passage literature. * Fishway consequences are organized into five categories: 1) movement delays and reduced fitness, 2) fallback, 3) ecological sink or trap, 4) selective passage, 5) species interaction and predation, and 6) introduction of non-native species above the barrier * The authors advocate for the use of a structured decision-making process to guide fish passage decisions. The SDM process can objectively evaluate the positive and negative consequences of providing fish passage. The article provides a brief overview of the SDM process and how it has been

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									applied in the Black Sturgeon River, Ontario. *Finally, the article outlines three examples of the SDM process: decision-analysis, real options analysis, and adaptive management.
OMNRF	2016	Black Sturgeon River Camp 43 Dam Project – Public Inspection of Draft Environmental Study Report	Canada - Ontario	Ministry of Natural Resources and Forestry. Ontario.	Walleye and Sturgeon.	N	Y	N	* This document outlines a draft environmental study that was posted on Ontario's Environmental Registry for public consultation regarding five options proposed to mitigate the structurally unsafe Black Sturgeon River dam (Camp 43 dam). * The draft environmental study evaluated slightly different options than those considered by the Fisheries Advisory Zone Council (Bobrowicz et al. 2010). For example, the preferred Zone Council option of "complete removal" of Camp 43 dam (with new barrier created at Camp 1) was not listed as an option in this draft report. Instead, the current draft environmental study report lists "partial" demolition of Camp 43 with the construction of a "multipurpose" dam at camp 1 as an option in place of complete removal. * The report outlines existing and historical conditions in the river with respect to ecosystem components. A review of Ontario's class environmental assessment process is provided because the dam falls within the jurisdiction of an Ontario Park and is therefore subject to a class review. *Restoration objectives for Walleye and Lake Sturgeon are provided, as well as Sea Lamprey control objectives. * A baseline context for current socio-economic values/uses in the watershed is also provided. *The study outlines, for each option alternative: 1) the cost in terms of operation and capital, 2) Walleye and Lake Sturgeon restoration potential, 3) Sea Lamprey control impacts and projected fish damage, 4) anticipated impacts to Brook Lamprey and juvenile Lake Sturgeon, and 5) connectivity restoration potential * A multiple accounts analysis was performed based on each option, to quantify and weigh the alternatives based on defined criteria. This was followed up with sensitivity analysis. *The report ends with construction and demolition impacts assessment and proposed mitigation for instream and residual effects, and socioeconomic

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									effects. *The report also addresses the concept of cumulative effects, in terms of dam operation and partial removal with respect to temporal and spatial boundaries of the effects.
Smyth, E., R., B., McLaughlin, R., L., Koops, M., A., Velez-Espino, L-A., Pratt, T., and Sullivan, P.	un pub	Trade-offs with improving fish passage: a case study of the Black Sturgeon Dam, Lake Superior	Canada - Ontario	RLM	Sturgeon, Walleye	Y	NA	NA	*Unpublished article that demonstrates the use of decision analysis (structured decision-making) to assess options for fish passage at a barrier on the Black Sturgeon River in Ontario, Canada. Specifically, decision analysis was used to quantitatively evaluate opposing management options for a dam that is a complete barrier to several important fish species: a species at risk, a commercially and recreationally important species, and an invasive species. *Opposing management options for fish passage arise because of the belief that the dam is preventing the rehabilitation of an important commercial species, Walleye, while also providing an important invasive species control for Sea Lamprey. *The goal of the decision analysis was to quantify the positive and negative consequences of providing passage at the dam by modeling the predicted impacts and the level of uncertainty associated with each positive and negative consequence. This allows decision-makers to quantitatively evaluate the trade-offs between various management options. * The authors took a three-step approach to the decision analysis: "First, we quantified the trade-offs between management options by projecting the expected abundances, and uncertainty about them, for sea lamprey, walleye, lake sturgeon, and northern brook lamprey, and the expected control costs, for each option. Second, we numerically evaluated whether blocking sea lamprey, while selectively passing walleye and lake sturgeon, could eliminate any trade-off between sea lamprey control and rehabilitation of walleye and lake sturgeon, without exposing northern brook lamprey above the dam to lampricides. Third, we numerically evaluated four uncertainties (hypotheses) that different stakeholders believed could alter projections of abundances for walleye and lake sturgeon"

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									* Here the authors use decision analysis to systematically incorporate the estimated uncertainty of each management option into simulation models that predict the outcome of each alternative management options for barrier mitigation. The outcomes are used as performance measures that are used to compare the different management options. *In order to predict the outcome for each species under each management option the authors developed a) baseline population models for each species, b) expected population models based on each fish passage option, c) models combining productive capacity to the availability of habitat (spawning for Walleye and Lake Sturgeon and rearing for Sea Lamprey) under each passage option, and d) models to predict the mortality of Sea and Northern Brook Lamprey by lampricide treatments under each fish passage option *The authors evaluated uncertainty by using low, medium, and high parameter values in the baseline models and by extending those baseline models to address the four additional hypotheses raised by stakeholders *The outcome of the decision analysis demonstrated that the predicted biological and economic outcomes for each management option differ substantially, as well as the value that stakeholders place on each outcome.
Bunt, C., M., van Porrten, B., T., and Wong, W.	2001	Denil fishway utilization patterns and passage of several warmwater species relative to seasonal, thermal and hydraulic dynamics	Canada-Ontario	Ecology of Freshwater Fish. 10: 212-219.	catostomids	N	N	N	*From 1995 to 1997 fish collection traps were placed at two Denil fishways on the Grand River, ON to assess passage capabilities of non-salmonid fishes. *Results demonstrated a shift in species catch composition in the fishway as water temperature increased from 8 to 25C. Fish species composition over the catch period changed from catostomids to cyprinids, to ictalurids, to percids and finally to centrarchids. *Fish upstream movement peaks were attributed to increased river discharge and increased turbidity. *The study focuses on upstream movement and does not address fallback rates, delayed migration/movement, or downstream passage over the low-head weir. *The study found that only a portion of the 29

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									freshwater fish known to inhabit the area near the two fishways were able to successfully ascend the Denil fishway.
Poff, N., L., and Olden, J., D.	2017	Can dams be designed for sustainability?	China	Science 358 (6368): 1252-1253	NA	NA	NA	NA	* This review provides a brief opinion on a recent article that evaluates the utility of a "designer flow regime" to promote sustainable fish populations in a system that is slated for the development of many large dams, the Mekong. * A designer flow regime has elements of environmental flow principles in that it aims to reduce the negative impacts of dams on the environment, while also ensure adequate power production, thereby reducing conflict and increasing valuable co-benefits. * Following an evaluation of fish-hydrology relationships, the original article predicted an increase in fisheries catch in a managed system with a designer flow regime, compared to the natural flow regime. The authors of this opinion article note that it is still unclear if a manufactured flow regime could support other aspects of the environment to ensure biodiversity and ultimately sustainable fisheries.
Don, A.	2015	Translating Regulation into Outcome: The eel's migration from statutory to physical protection	Europe	International Conference on Engineering and Ecohydrology for Fish Passage 2015	European Eel	N	Y	Quantitative	* This presentation on European Eel directive under the Water Framework Directive (WFD) was presented at the International Conference on Engineering and Ecohydrology for Fish Passage 2015. * The purpose of the presentation was to provide insight on why the regulation was developed, and how it is being implemented by member states of the EU. * The regulation requires that member states with watersheds that contain or historically contained European Eel develop eel management plans. These plans must identify measured that member states intend to take and what areas of management the plan will address. The plans are to be watershed based regardless of political boundaries and should not be delayed due to timelines associated with transboundary watershed planning. * Specifically, the directive states that: "The objective of each Eel Management Plan shall be to

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									reduce anthropogenic mortalities so as to permit with high probability the escapement to the sea of at least 40 % of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock. The Eel Management Plan shall be prepared with the purpose of achieving this objective in the long term." Regulations supporting the directive outline how targets should be calculated and calls for an implementation schedule for each management plan. * For example, England and Wales passed a subsequent eel regulation that requires provisions for eel passage such that where passage is or may be impeded, the obstruction must be removed or effective eel passage installed (at the owner's cost), and where appropriate abstraction intake screens be installed. A risk-based approach to implementation of the passage regulation was undertaken based on considerations related to habitat quality and quantity available as a result of mitigation, cumulative downstream barriers, and distance from head of tide.
Larinier, M.	2008	Fish passage experience at small-scale hydro-electric power plants in France	Europe	Hydrobiologia. 609: 97 - 108	NA	NA	NA	NA	*This article outlines the contribution of small hydropower facilities to the total annual energy generation of France and highlights the substantial (1000 MW) growth potential of small hydropower. * A limitation to fully realizing the hydroelectric potential in France is specific environmental legislation such as the French Environment Code that requires any hydro facility, in a designated watercourse, to include a facility that guarantees passage of migratory fish. All facilities must comply with the directive within 5 years of the publication of a list of migratory species by river basin and or sub-basin. * The diadromous migratory species covered by the Code are Atlantic Salmon, sea-run Brown Trout, Sea Lamprey, Allis Shad, Sturgeon (*Acipencer sturio*) and European Eel. The only riverine species considered to be 'migratory species' are Brown Trout, Northern Pike and European Grayling. *Despite the Code, fish passes are generally now required by regulators for all new hydro facilities and relicensed facilities on rivers that are not

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									classified as "migratory" by the Code. This is to facilitate passage for riverine species and promote longitudinal connectivity in rivers as required by the Water Framework Directive. * The French Environmental Code also requires hydrofacilities to guarantee a minimum ecological flow standard for the river to ensure continued existence, passage and reproduction of the species that populate the watercourse. The owner of a hydrofacility must also achieve free circulating of fish around the barrier which necessitates knowing the efficiency of a particular fish pass. *The article outlines the difference between fish pass effectiveness and efficiency as: "Effectiveness of a fish pass is a qualitative concept, which consists of checking that the pass is capable of letting all target species pass through within the range of environmental conditions observed during the migration period, whereas the efficiency of a fish pass is a more quantitative description of its performance. It may be defined as the proportion of stock present at the dam which then enters and successfully moves through the fish pass in what is considered to be an acceptable length of time." *The author points out that the largest issue with evaluating fish passage for a population is the cumulative impact of a series of hydrofacilities on a watercourse or river system. For example, the author notes that " Considering passage at 10–20 plants, even with a high mean survival rate of 95%, or even 98% at each plant, the cumulative mortality rate will be, respectively, between 40 and 19% and 74 and 33%. These indiscriminate impacts of small-scale hydroplants can threaten entire fish populations."
Fjeldstad, H-P., Pulg, U., Forseth, T.	2018	Safe two-way migration for salmonids and eel past hydropower structures in Europe: a review and recommendations for best-practice solutions	Europe	Marine and Freshwater Research. 69 (12): 1834-1847	Salmon and American Eel	Y	Y	Y	*This report provides a summary of the existing knowledge of how to implement two-way passage of salmonids and eels at hydroelectric facilities in Europe. The report makes broad recommendations for preferred passage structures including eel ramps and nature-like bypass channels, and vertical-slow fishways. The report also recommends operational changes to promote safe passage such as reducing the drop between pools in pool and weir fishways, and to reduce energy dissipation.

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									*The authors note that "two-way" passage does not imply one pass structure to facilitate up and downstream movement, but separate solutions to ensure migration in both directions. * Best practices are stated as achieving passage with minimal delay and efficiency targets lower than 100% as it is often infeasible to attain 100% efficiency (due to natural processes and anthropogenic influences). A passage efficiency target of 90% is provided as "customary". * The authors note that large global reviews of fish passage have suggested that for rivers wider than 100 m, at least two fishway structures should be provided unless the only target species is Atlantic Salmon where one facility may be sufficient. * The authors note that unless no other option is feasible due to the height of a barrier, trap and truck pass options should be avoided due to their selectivity, intensive labour requirements, and on-going financial border in the long term. *The authors also address the impact of cumulative mortality at successive barriers as a major limitation to fish passage efficiency on a watershed or population scale (e.g., if 10 barriers exist each with 90% passage survival, total passage survival will only be 35%).
Baudoin, J-M., Burgun, V., Chanseau, M., Larinier, M., Ovidio, M., Sremski, W., Steinback, P., and Voegtle, B.	2015	Assessing the passage of obstacles by fish: Concepts, design and application	Europe - France	French National Agency for Water and Aquatic Environments	Whole Community	N	N	N	*In order to meet various national and international commitments related to freshwater ecological status (e.g., WFD) the authors of this document provide a thorough upstream passage assessment protocol to determine the impacts of barriers on river flow and movement of the common freshwater fish species of France. * The protocol does not assess passage metrics of barriers for downstream fish movement. * The protocol provides guidance on how to identify a barrier, and the potential for fish pass installation, based on the barrier's construction and hydraulic conditions of the site, and then comparing the results to the physical capabilities of local species. * Fish species were combined into groups based on their swimming capabilities, including maximum swimming speed and minimum required water depth, and their jumping capabilities. Only adult, or sexually mature, life stages were considered

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									(except eel). The only motivation for movement considered was migration for reproductive purposes (except for eel). *The goal of the protocol was to develop a rapid (< 2 hours) assessment technique to determine if a barrier impedes fish passage
Breve, N., W., P., Buijse ,A., D., Kroes, M., J., Wanningen, H., and Vriese ,F., T.	2014	Supporting decision-making for improving longitudinal connectivity for diadromous and potamodromous fishes in complex catchments	Europe - Netherlands	Science of the Total Environment. 496: 206-218	diadromous and potamodromous	Y	Y	NA	*The authors of this report provide a national scale barrier removal / mitigation prioritization tool to meet the goal of the EU Water Framework Directive (WFD) that all freshwater systems must be in good ecological status by 2015 and the directive that all barriers significantly hampering migration must be mitigated or removed by 2027. * According to the WFD, fish are a key biological indicator to assess ecological status. Evaluations have occurred in the Netherlands to set objectives for fish community composition based on waterbody type and classification. * The report highlights that potamodromous species require migratory corridors free of obstruction to carry out their life processes in certain situations, and that barriers can lead to genetic isolation and restrict populations to small, low quality habitat between barriers that may ultimately reduce population viability. In such situations barrier mitigation for potamodromous species is required. * The authors provide a decision-making framework to assess passage based on grouping species into functional guilds. The guilds are based on linking waterbody classification with spatial distribution of barriers to the habitat requirements and migration routes of the species guilds. *The framework identifies anadromous fish and long-distance migrants as the highest priority for barrier mitigation prioritization. The tool prioritized barriers that would benefit the most guilds given barrier removal or mitigation. *The prioritization tool does not appear to consider cumulative impacts from multiple barriers nor the potential negative impact of increasing habitat accessibility of invasive species.
Kemp, P., S.	2016	Meta-analyses, metrics and motivation: mixed	Global	River Research and Applications.	NA	N	N	N	* This review article outlines the rising debate over whether or not the negative environmental impacts caused by dams on migratory fish populations can be mitigated through engineered solutions.

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		messages in the fish passage debate		32: 2166-2124					Ultimately, the debate centers on whether or not fish passes can in fact offer utility and transferability to multiple species and regions. * The author points out that in many cases, formalized policies and management plans for fish passage do not account for the growing body of evidence that suggests fish pass mitigation technology often fails to meet its intended goal or objective. * Often it is hard to determine the success of a fish pass because few studies have monitored the target species and individuals past the fish passage facility of interest. *The article provides a review of recent literature that has demonstrated the variation in fish pass efficiency and also how meta-analyses of efficiencies are complicated by site specific hydraulics. The author also points out that traditional fish pass performance metrics may be inappropriate for fish non-salmonid fishes that have alternative life history strategies and movement behaviours. *Summarized in the article are various studies on fish pass efficiency estimates and implications for different fish species. * The author concludes that: "Future resource planning and management must be based on well informed decision-making processes that recognize the variability in fish passage effectiveness, and that it will usually provide only a partial solution, and in some cases can lead to negative outcomes".
Kemp, P., S., and O'Hanley, J., R.	2010	Procedures for evaluating and prorating the removal of fish passage barriers: a synthesis	Global	Fisheries Management and Ecology. 17: 297-322	NA	Y	NA	NA	* The authors of this article provide a review of the techniques used to assign the impact of barriers for use in prioritization tools for restoration. Unsurprisingly, the authors find that most assessment criteria for barrier impact are based on the swimming abilities of adult salmonids. *The article calls for the use of optimization modelling to inform decisions about river restoration across watersheds and argue that simple cost-benefit analyses (e.g., rank order) are insufficient because barriers are considered in isolation. * Fish pass efficiency varies depending on if a study is examining efficiency of a pass for an individual (e.g., number of individual pass attempts before

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									success), or at the population level (proportion of the population that passes relative to all those that arrive at the barrier). In some cases, barrier passability is based on subjective expert opinion without field validation. * Habitat quantity is often used to assess the magnitude of the benefit of barrier mitigation, but it is more often that habitat quality is required to accurately predict benefits of mitigation, which is seldom considered. *The authors note that habitat suitability indices may be useful to assess habitat quality and quantity upstream of a barrier but warn that such information if often lacking for non-salmonids. *Most barrier prioritization tools focus on scoring systems that weigh the benefit of habitat quality, habitat quantity, measure of improved passage, against the cost of mitigation. However, the authors find that "By ignoring the spatial structure of multi-barrier networks, highly inefficient solutions can be produced in which the removal of some barriers results in no net habitat gain for the target species of interest ". * Barrier prioritization tools should systematically consider the interconnectedness of barriers as well as budgets and benefits to species. * Several examples are provided demonstrating the use of optimization models in assessing whole system benefits, risks, and costs associated with barrier mitigation at a watershed scale.
Liew, J., H., Tan, H., H., and Yeo, D, C., J.	2016	Dammed rivers: impoundments facilitate fish invasions	Global	Freshwater Biology. 61: 1421-1429	NA	N	N	NA	* In this article the authors review the global literature on changes in fish species composition and abundance as a result of barrier created impoundments and reservoirs. The authors compare their findings to undammed, free-flowing rivers. * Dam construction was not found to statistically alter the richness or abundance of fish species found in reservoirs compared to free-flowing conditions, because the loss of riverine specialists was compensated for by the increase in lentic specialists. The authors found that when native lentic specialists were not immediately available to colonize the reservoir, alien species often exploited the habitat. This resulted in impoverishment of

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									native species richness while overall species richness was maintained. * Older impoundments were found to host a larger proportion of alien species.
McKay, S., K., Cooper, A., R., Diebel, M., W., Elkins, D., Oldford, G., Roghair, C., and Wieferich, D.	2016	Informing watershed connectivity barrier prioritization decision: a synthesis	Global	River Research and Application. 33 (6): 2-16	NA	Y	NA	NA	* A large review paper, this article synthesizes 46 watershed-scale barrier planning studies in order to develop guidelines to inform barrier prioritization decision-making focused on restoring connectivity for aquatic species. * The purpose of the article was to provide a consistent and transparent model for spatial prioritization for barrier mitigation. Mitigation was used to represent removal or repair of a barrier, or the installation of fish passage. From a review of the literature, a set of six common barrier prioritization steps were identified to aid decision-making. Only 4 of 46 studies evaluated barrier repair or fish passage installation while 42 prioritized barriers for removal. Common Barrier Prioritization Steps: "* Step 1: Identify the scope of the analysis: including geographic scope, focal taxa (s) and their requirements, presence/threat of invasive, types of management actions/options (e.g., partial or full passage) * Step 2: Develop a geospatial database involving common data sources such as: spatial model of stream network, anthropogenic barriers, natural barriers, habitat quality and quantity, passability estimates, removal cost estimates. Few studies address habitat quality beyond a general notion of the expected home range of a focal taxon. Future prioritizations should include measures of habitat quality. * Step 3: Predict connectivity for the watershed such as incorporating systemic indices of connectivity into prioritizations. Many connectivity metrics are based upon coincidence probability and cumulative pass ability between fragments, which can be further subdivided into those metrics reflecting diadromous and potamodromous life histories * Step 4: Compute costs and benefits of alternative scenarios. This leads to two important considerations for decision makers: (I) the choice of effort (e.g., budget) can

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									impact the efficiency of restoration efforts (Neeson et al. 2015) and (ii) evaluating costs and benefits of individual projects is typically a task distinct from evaluating multiple projects at once. The ultimate objective of barrier prioritization is to identify a cost-effective solution for any budget or desired degree of connectivity. * Step 5: Summarize information for decision making and take action * Step 6 - post-project monitoring " *Regarding cost benefit analyses the authors note that three methods are commonly used including complete enumeration, scoring and ranking, and optimization. They note that the static nature of scoring and ranking methods does not account for spatial interdependence and can lead to inefficient outcomes for barrier prioritization.
Noonan, M., J., Grant, J., W., A, and Jackson, C., D	2012	A quantitative assessment of fish passage efficiency	Global	Fish and Fisheries. 13: 450-464	Salmonids and non-salmonids	NA	NA	NA	* This article provides a meta-analyses of fish passage efficiency of structures that were built between 1960 and 2011. The efficiency of a passage structure was evaluated separately for salmonids, and non-salmonids. All non-salmonids were grouped due to the limited amount of data for non-salmonid species. * The authors found that upstream passage was less efficient compared to downstream passage (41.7 to 68.5%) and that salmonids were more successful at passing both up and downstream than non-salmonids. *Based on the studies evaluated, the authors found that certain structures provided better passage efficiency (pool and weir, pool and slot, natural fishways) compared to others (Denil fishway and lock/lifts). Longer fishways and those with increased velocity increased passage efficiency whereas increased slope decreased efficiency. In this article three elements of efficiency were evaluated: 1) attraction efficiency - proportion of migrants able to locate the fishway, 2) entrance efficiency - percentage of migrants that entered the fishway, and 3) passage efficiency - percentage of fish present in the fishway (1 and 2) that successfully ascended the barrier. * The study does not evaluate if the ecological endpoint and motivation for movement was achieved. Nor were migration delay, or fallback

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									evaluated. * Importantly, the authors note that " However, only the very best designed fishways are approaching 100% success, which would satisfy Canada's 'No Net Loss' policy. Indeed, the average fishway in our data set allowed only 62% of salmonids and 21% of non-salmonids to pass upstream. Application of the precautionary principle would imply that the average barrier equipped with a fishway reduced the productive capacity of the ecosystem by about 50%."
Olden, J., D.	2016	Challenges and opportunities for fish conservation in dam-impacted waters. Pages 107-148 in *Conservation of Freshwater Fishes* (Eds. Closs, G.P., M. Krkosek, and J.D. Olden).	Global	Conservation of Freshwater Fishes	NA	N	NA	NA	* The author of this book chapter outline that fish passage mitigation options are largely ineffective, and that dam removal provides a more holistic and successful approach to increasing access to habitats, restoring migratory routes, increasing genetic connectivity, but also limiting power production and increasing available habitat to invasive species. * Statistics regarding the myopic view of North American fish passage are provided: only 4% of North American fishway studies examine the entire fish community compared to Europe (38%) and Australia + Africa (~98%). * The impacts of dams on migratory species are discussed
Silva, A. T., Lucas, M. C., Castro-Santos, T., Katopodis, C., Baumgartner, L. J., Thiem, J. D., Aarestrup, K., Pompeu, P., O'Brien, G. C., Braun, D., Burnett, N. J., Zhu, D. Z., Fjeldstad, H. P., Forseth, T., Rajaratnam, N., Williams, J. G., and Cooke, S.	2018	The future of fish passage science, engineering and practice	Global	Fish and Fisheries. 19: 340-362	NA	NA	NA	NA	* A recent and large synthesis paper, this article summarizes the changes in fish passage science and practice from its beginning as an engineering focused field to a multi-disciplinary approach encompassing engineering, conservation, and socio-economic considerations. * Today, effective fishways are those which result in minimal passage delay and limit or eliminate post-passage impacts. The authors state that to achieve such effectiveness, adaptive management approaches and innovation are required. The goals for fish passage must be clearly stated and weighted against fisheries management objectives. * To be effective, fishways must consider the fish community and life history of target species for passage, including migratory and dispersal movements, along with potamodromous movements. *The fishways of tomorrow need to be "easier" for fish to pass and consider changing conditions (e.g.,

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									climate change) where warmer waters or changes in flow may alter the swimming capabilities of target fish species. * The authors note that if fishways fail to be effective the cost to the natural capital and ecosystem services can be extremely high over the long term; they call for the incorporation of ecosystem valuation during options development for maintaining aquatic connectivity and restoration. Socio-cultural values must also be incorporated, and this process is typically undertaken during the development of watershed or fisheries management plans with specific and measurable fisheries management objectives. * The authors state, importantly, that effectiveness of a fishway can no longer be measured simply as whether or not a fish can locate and access a fishway and that broader spatiotemporal aspects must be considered, at the catchment scale. * An example is provided that of the 92 freshwater species in Canada that are migratory, we understand the movement behaviour of less than 1/3 of those species. As such, it is difficult to design effective fishways for a large portion of the fish community. *Because fishways are expensive, and the cost to the ecosystem of constructing an ineffective fishway can be astronomical, a better way to understand fishway effectiveness towards meeting stated objectives against alternative outcomes needs to be developed. Alternatives must also consider providing no passage at a barrier, or physically removing a barrier. * The literature does not provide sufficient evidence to suggest that a single fishway will effectively pass more than a few select target species and therefore would be ill-suited to meet community wide objectives. *The authors call for stronger rationales as to why specific targets and criteria are used to define what is "acceptable" fish passage efficiency. * Construction of fishways for the passage without considering up and downstream mortality, delay, and availability and quality of necessary habitats will lead to insufficient protections for maintaining target species.

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									*The authors note a lack of understanding of other passage impacts such as individual fitness, delay, physiological stress, fallback rates, carry-over effects, and altered population distribution. Long-term, post-construction monitoring data is lacking or publicly unavailable which makes understanding the long-term effects of fish passage difficult to quantify. *Effective fish passage can only be obtained when we understand the natural levels of migration success and failure and have a thorough understanding of the proportion of a population that needs to be passed (up and downstream) to ensure population sustainability.
Gísli Már Gíslason,	2016	Is it possible to reach a consensus on the utilization of catchments and geothermal areas for energy production?	Iceland	Aquatic Conservserti on Marine and Freshwater Ecosystems: 26: 619–622	NA	Y	Y	NA	*This opinion article describes the holistic approached used in Iceland to identify areas for potential energy development at the national level. the process was based on a similar Master Planning process undertaken in Norway. This process aims to reduce conflict between various groups by identifying protected areas, areas where more information is required, and areas identified for energy development. The process is holistic and evaluates cumulative development potential, and harm, to assess the best options at a national level (and discourages one-off, isolated, decision-making). * The process was undertaken as part of the Icelandic Master Plan for Nature Protection and Energy Utilization. The process to develop the master plan was based on input provided by four expert groups: (a) assessing nature conservation and cultural heritage value; (b) other land use (e.g., grazing and tourism); (c) effect of energy development on regional development; and (d) the energy production cost. The Master Plan was made available for public consolation and input across the country. * The plan will be used to inform Parliamentary resolution development to provide for protection of river basins, and prioritization for energy development (hydro, geothermal, and wind). * Each of the four expert groups developed criteria to assess their respective categories and methodologies were reviewed across expert groups. The largest challenge was assessing the

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									"value" of nature related indicators. For example, the conservation and cultural values were assessed based on: "The geology, groundwater and water bodies; biota (plants, birds, fish, freshwater invertebrates and thermophilic bacteria); landscape and wilderness; and cultural heritage were ranked according to (1) diversity and richness, (2) rarity, (3) size (area), completeness and pristineness, (4) information and symbolic value, (5) international responsibility, and (6) scenic value." * "Standardized attribute scores were used to derive total class scores whose weighted sums yielded total site value and total impact. The final output was ranked by an Analytical Hierarchical Process (Saaty, 2008) considering total predicted impacts, total site values, risks and uncertainties as well as special site values (Thórhallsdóttir 2007a)."
Franklin, P., Gee, E., Baker, C., and Bowie, S.	2018	New Zealand Fish Passage Guidelines for Structures up to 4 m.	New Zealand	Government of New Zealand	NA	N	N	N	*This Government of New Zealand guideline document provides practitioners with guidance for the assessment and development of fish passage structures on small (<4 m) barriers. *The extensive document provides guidance related to fisheries values, the legislative context, planning and design considerations, design requirements for structures, remediation options, barriers for the purposes of limiting invasive species movement, and monitoring. *Under the authority of various pieces of legislation, Regional Policy Statements and Regional plans provide an overview of resources management issues in a region and govern how those resources will be used. The National Policy Statement for Freshwater Management is implemented through the regional planning framework and the Statement defines ecosystem health as a national value. The Statement mandates that ecosystem health is maintained or improved in freshwater ecosystems. Due to the impacts of instream structures, those impacts need to be mitigated to achieve the mandate of the Statement. * The report outlines that clearly defined and justifiable ecological objectives must be used at each structure to inform the development of fish passage objectives at a site. The fish passage objectives will inform the development of

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									performance standards. Performance standards fall into two categories: 1) Biological Performance Standards 2) Physical and Hydraulic Performance Standards. *The fish passage objectives should identify target species for passage, the species abundance and distribution, and recovery potential for species in decline, as well as information on migration life-stage and when and under what conditions migrations occur. * The guide follows the alive of O'Connor et al.(2015), who states that performance standards should be assessed against ecological and fish passage objectives, and that biological performance standards can be divided into three categories: 1) changes in fish distribution and abundance, 2) proportional passage of a life-stage of target species under differing flows, and 3) delay in passage of a life-stage under differing flows.
Hawke's Bay Regional Investment Company Limited	undated - after 2012	Report to Decision-Maker	New Zealand	Department of Conservation	Native migratory fishes	Y	N	N	* The purpose of this report is to provide a thorough analysis of the application (Ruataniwha Water Storage Scheme) by Hawke's Bay Regional Investment Company Limited to construct a large dam and fish barrier. The analysis considers the effects within the context of the Freshwater Fisheries Regulations 1983 and was written by Department of Conservation staff to inform the regulator (decision-maker). * The construction project is described as: "The RWSS involves the construction of an 83m high dam to store approximately 90 million cubic meters of water for the irrigation of the Ruataniwha Plains and Papanui Basin Area in the Central Hawke's Bay Region. The dam is proposed to be located in the upper Makaroro River and will include part of the Ruahine Forest Park. It is envisaged that this dam will harvest winter and other high flows to provide reservoir supply for between 25,000 and 30,000 hectares of land. This will create a surface lake area of 370ha, extending almost 7km upstream of the dam." * Regulation 1983 (Fisheries Act) - Part 6 - provision 41-47 describes that a fish facility for passage is required if Director-General deems it necessary. Fish is not defined as a particular or select assemblage of species. Targets for passage or

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									goal setting is not discussed in the regulation. * The Conservation staff provide a summary of the mitigation and offsetting plan provided by the proponent as: " To mitigate the effects of the dam, (noting the effects of the footprint of the dam and the reservoir on the natural environment are irreversible changes to the natural environment), the Applicant proposed the following: 1) Mitigation and offsetting including removal of barriers to fish migration in surface water bodies in the Tukituki and Heretaunga Plains catchments, riparian planting, spring-fed stream enhancement and priority sub-catchment phosphorus management, collectively referred to as the Integrated Mitigation and Offset Approach ("IMOA"). 2) As part of the IMOA, a trap and transfer regime for native migratory fish, facilitating movement for species both above and below the dam structure. The Applicant submits that the IMOA offered will be more effective than an alternative fish facility option (such as an engineered fish pass or canal)." * District Conservation office provided comments on proposed mitigation options: These comments note that fish passage is impractical given the specifications of the proposed structure. The Conservation Services Manager notes that mitigation measures regarding fish facilities had been discussed at length prior to the submission of the application. The District Office supported the trap and transfer option for eels but not for other species, and instead suggested barrier removal options. * The report notes that the regulations do not allow for the Director-General (decision-maker) to pass a decision on the construction of the dam, rather, the Director-General can only inform the requirements for fish passage and should assume the barrier is a "given". * Of the trap and transfer program, 8 experts provided comments that outlined there is considerable uncertainty regarding the program to meet passage or sustainability objectives, but 5 of 8 experts agreed that the trap and transfer program was the best mitigation option. The board noted that the trap and transfer program would not mitigate all of the effects of the environmental dam.

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									* For the purposes of the application review, fish passage effectiveness was defined as the likelihood of meeting the management objective of "maintaining the existing fish community composition upstream of the dam". However, the trap and transfer program were designed primarily for two target species. Experts noted that the low flow reservoir conditions will not be conducive to downstream movement of larval from several important species. Several experts also commented that the trap and transfer program has been demonstrated to be ineffective at other large dams in NZ and that specifically eel downstream movement will be hampered by such mitigation options. * However, department considered trap and transfer sufficient and would protect indigenous fisheries. * The report notes that department staff were considered with the proposed performance target for the trap and transfer program, which was very limited: "ensure that the trap and transfer programme is enabling successful recruitment of eels". The staff recommended that the target be altered to specific target fish species as though known to be present at the dam.
Pelicice, F., M., and Agostinho, A., A.	2008	Fish Passage Facilities as Ecological Traps in Large Neotropical Rivers	South America	Conservation Biology. 22 (1): 180-188.	NA	NA	Y	NA	* This article outlines the unintended consequence of fish passage structures in neo-tropical watersheds (South America) where upstream passage has resulted in an ecological sink. * The authors outline the conditions that result in fish passage promoting an ecological sink: 1) fish are attracted to the fishway, 2) only unidirectional movement is facilitated, 3) the upstream environment does not support successful recruitment, and 4) the environment downstream of the barrier has sufficient conditions to support a sustainable population. * When fish ascend a fishway into poor quality / quantity of habitat with no safe downstream passage, the fish is subjected to reduced fitness and poor recruitment is likely to result in depletion of the downstream population. * The lack of adequate spawning habitat upstream is not the only negative effect of providing

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									unfettered passage. Where spawning habitat is available upstream but rearing conditions are poor (e.g., reservoir) larval and juveniles spawned upstream may languish and die in unsuitable habitats or during unsuccessful downstream migration attempts. * The authors argue that decisions regarding why, where, and how fish passage is installed should be based on ecological information and that long-term post construction monitoring must be conducted to assess effectiveness. * A key point is made that passage cannot be managed in a "trial and error" fashion or based solely on the assumption that fish must migration to complete their life cycle.
Oldani, N., Baigun, C., R., M., and Delfino, R., L.	2005	Considerations sobre el funcionamiento de los sistemas de transferencia para peces en las represas de los ríos de la porción inferior de la Cuenca del Plata*	South American - Argentina	INSUGEO, Miscelánea. 14: 367-382	NA	NA	NA	NA	* Google Translate was used to translate this article from Spanish. Caution should be used when interpreting this article in the event of inappropriate translation. * The article discusses the performance of fish passage systems in the Rio De La Plata Basin (which is a transboundary watershed encompassing southeastern Bolivia, southern and central Brazil, the entire country of Paraguay, most of Uruguay, and northern Argentina). * The authors suggest that fish passage design and installation in South American has lacked necessary background information to make informed, effective decisions. In the basin, salmonid-centric pool and weir systems have regularly been installed at barriers, whereas at larger barriers in the lower basin fish lifts (elevators) have been installed. * Elevator efficiency is stated as < 1% for native migratory species due to impractical designs and poor location. * The authors provide a summary of efficiency studies at one fish lift in particular and report that: "*Between 1995 and 1998, the total efficiency of the elevators was very low, less than 2% and noticeably less than 7% predicted by Colin (1997). The target species, the most important of the fishery, they reached only 0.6%. The shad was the most abundant with 2.5% of that total but represented 30% in experimental fisheries (Oldani et al. 1998). In the elevators they identified 36

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									species that represent 44% of the total registered in experimental fishing, suggesting that the fish have difficulties to enter the transfer systems" * Studies have demonstrated that the cost per individual (considering fish lift construction and maintenance) is extremely high given the limited and inefficiency fish passage. The authors argue that at less than 10% efficient a fish lift is extremely costly per individual that is worthwhile to invest in a new fish passage design system that can effectively meet ecological and fisheries objectives.
Pompeu, E., S., Agostinho, A., A. and Pelicice, F., M.	2012	Existing and Future Challenges: The concept of successful fish passage in South American	South American - Brazil	River Research and Applications. 28: 504-512	NA	Y	Y	NA	* This article outlines the negative consequences of providing ill-designed fish passage at hydrofacilities for migratory fish communities of Brazil. * Despite the high cost of installation, maintenance and effort, fish passage has been installed with little demonstrated effectiveness to achieve sustainable populations. * The mismatch between evaluating efficiency and achieving sustainable populations can be linked to inappropriate measures of "efficiency" or effectiveness. The authors propose a new concept to estimate efficiency based on a fishways ability to maintain viable fish populations. * Brazilian legislation states that fish passage and/or hatchery facilities to stock juveniles in reservoirs are required for important migratory species to mitigate the effects of dams. However, the continued decline of migratory species and reduced fishery productivity have demonstrated that the strategy is not working as intended. * Efficiency in Brazil has typically been evaluated as the ability of a fish to ascend a ladder and does not consider ecological endpoints that motivated the migration/movement. That is, existing studies do not evaluate if fish passage has achieved the ecological endpoint. * The authors argue that effectiveness of fishways as conservation tools must incorporate considerations of the up and downstream habitat quality/quantity, and the feasibility of downstream movement of all life-stages. * It is demonstrated that in Brazil fishways are not selected allowing many species to enter the structure, but that only few species are able to

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									successfully ascend the fishway. It is also shown that downstream passage assessments are rare. While the fishway should allow for downstream movement, the ecology of native species suggest the majority of migratory species will not pass through the unhospitable reservoir to return downstream. This creates a population sink situation where adults from a downstream population move upstream and do not return, and reservoir conditions do not promote safe passage of larva or juveniles downstream. * The authors state that " Fish passage considerations must include efficiency of all species of interest, number of obstacles and placement in the river, and biological and conservation objectives", and note that passage does not ensure recruitment. *In order to maintain fisheries opportunities upstream of a barrier, a sustainable proportion of the population may be passed, and this will also help to reduce population fragmentation.
Bernstein, B., and Iudicelle, S.	2002	Decision Analysis: Can it provide an effective tool for fisheries management?	USA	National Fisheries Conservation Centre	NA	N	NA	NA	*This document provides a summary of workshop proceedings and discussions held at a National Fisheries Conservation Centre workshop focused on assessing the utility of decision analysis in fisheries management. * Key presentations are summarized that highlight examples of decision analysis being used in fisheries management (e.g., Atlantic Bluefin tuna decision analysis to evaluating risk of two stock assessment scenarios). *The document summarizes workshop participants consensus on the pros and cons of using decision analysis in fisheries management (e.g., pro - decision analysis is a framework that integrates scientific information and values-based preferences which can reduce conflict, and con - it can take a lot of time and resources to develop and implement the decision analysis model and there is a general lack of awareness of this approach)
Birnie-Gauvin, K., Franklin, P., Martin, W., and Aarestrup, K.	2018	Moving beyond fitting fish into equations: Progressing the fish passage debate in the Anthropocene.	USA	Aquatic Conservation : Marine and Freshwater Ecosystems. 2018: 1-11	NA	NA	NA	NA	* This review article provides a practitioner's perspective of the most prominent issues regarding fish passage in terms of the management and conservation of freshwater ecosystems. * The authors note that fish passage is often a secondary consideration and fish are "fit into the

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									equation" of design, where the concept of "impair then repair" is the dominant approach. But the authors argue that a holistic approach to moving fish around barriers should be taken when considering engineered solutions. * The trade-offs between ensuring food security and access, energy, safe drinking water and ecosystem services need to be considered to ensure sustainable river basin development. * The authors highlight the site-by-site approach to most fish passage design and the lack of a watershed or holistic approach to planning and understanding fish passage. * The literature is often lacking, or is contradictory, regarding species movement patterns. The authors suggest that downstream screens and bypasses have been promoted as safe downstream passage options for smolts that migrate at the surface, but that some studies show as many as 60% of smolts move below the screen or near the river bed. * The authors also review the definition of migratory vs non-migratory and point out the prevalence of passage options for obligatory migratory species, whereas facultative migratory species or species that rely on movement for dispersal are often ignored and considered not significantly impacted by barriers. * Habitat suitability and availability following the construction of a barrier is often not considered prior to the installation of fish passage, such that even if a species can overcome a barrier, there may still be negative population viability consequences. *Where most fish passage efficiency studies focus on performance standards that assess fish entrance and ascent, and not whether or not the passage structure has ensured population viability, it is difficult to address passage effectiveness holistically. * The authors also call for informed, and publicly available results of post-construction monitoring. Specifically, they state: "Herein lies a critical challenge both for fish passage scientists and practitioners: How can objectives for fishways (or more broadly for maintaining connectivity) be defined that are ecologically meaningful but which are also

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									practicable (i.e., specific and measurable)? The lack of post-implementation monitoring is a lost opportunity. Understanding how existing mitigation efforts work and do not work may yield significant information that will help improve future rehabilitation efforts (Birnie-Gauvin, Tummers, et al. 2017). To achieve this, however, there needs to be guidance on what to monitor and how, and this relies on having clearly defined objectives. Definitions such as 'effective' or 'free' fish passage can be ambiguous, open to interpretation or unachievable." * Monitoring questions should address the questions that answer key ecological questions such as: what proportion of the fish arriving at a dam are able to pass? And how many fish are required to pass to meet ecological objectives and ensure population sustainability?
blackBear Hydro Partners	2013	Revised Species Protection Plan and Revised Atlantic Salmon Passage Study Plan for Project Nos. 2710, 2712, 2534, 2600, and 2666 (Orono, Stillwater, Milford, West Enfield, and Medway Hydroelectric Projects)	USA	Sarah Vogel	Salmonids	N	N	Y	* This proponent report to the regulator (Federal Energy Regulatory Commission, FECR) outlines how the proponent company will modify operations, research, and monitoring of species in the Penobscot River to meet species protection requirements as per its FERC water and energy license. * The proposal outlines upstream and downstream passage performance standards for "effective" fish passage. For example, "The performance standard for downstream migrating Atlantic salmon smolts at the Orono, Stillwater, Milford, and West Enfield Projects is 96% survival at each project, evaluated by being within the lower and upper 75% confidence limit. That is, 96% of downstream migrating smolts approaching the dam structure survive passing the project, which would include from 200 meters upstream of the trashracks and continuing downstream to the point where latent effects of passage can be quantified." * The proponent outlines several actions that will be undertaken if operational monitoring reveal that performance standards are not met, for example "If annual project survival from three years of monitoring does not meet the performance standard, then Black Bear will do the following to meet the performance standard: 1) Provide two weeks of 100% spill of river flow at night (8 p.m. to

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									4 a.m.)(i.e., turbine shut-downs except for one unit, which will be operated at its lowest possible setting as required for powerhouse startup) starting when water temperature in the river reaches 10°C, 2) Followed by two weeks of spill of 25% of river flow during day and night." * It should be noted that these adaptive mitigation options are limited to flow regime changes and not long-term structural changes. * The proponent operates a Denil fishway at its Milford dam that has operational dates consistent with the migration period for several key species including Atlantic Salmon, shad, among others. An eel ladder is also installed at the center of the spillway. Downstream passage is provided through a bypass that empties into the tailrace. *As a result of the FERC relicensing process several new conditions were placed on the proponent such as the installation of a new downstream passage facility and a new fish lift and handling facility. The proponent was also required to reduce the clear bar spacing at the inner trashrack to 1 inch to full depth. The fish lift will be associated with a sorting facility and a trap and truck program to move fish over the barrier.
Bowman, M., Higgs, S., Maclin, E., McClain, S., Sicchio, M., Souers, A., Johnson, S., and Graber, B	2002	Exploring Dam Removal: A Decision-Making Guide	USA	American Rivers and Trout Unlimited	NA	Y	Y	N	* A non-governmental organization manual (American Rivers and Trout Unlimited) to guide dam removal decision-making. The purpose of the document is to provide guidance to identify all costs and benefits associated with dam removal, or retention. The report does not provide a mechanism to balance the costs and benefits. * The report states that the factors that influence cost-benefit analyses are complex and vary from case to case. Factors that will influence decision-making include site specific ecological and sociological circumstances, the complexity of the issue, legal and political context, the impetus for removal (dam safety vs fisheries), who the decision-maker is, public support or contest, the number and capacity of stakeholders. * The report provides general information to aid in understanding several key themes related to dam removal and fish passage: considering dam removal, decision-making, ecological issues,

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									economic issues, societal issues, and technical and engineering issues
Brown, J, J., Limburg, K, E, Waldman, J., R., Stephenson, K., Glenn, E., P., Juanes, F., and Jordaan, A.	2013	Fish and hydropower on the US Atlantic coast: failed fisheries policies from half-way technologies	USA	Conservation Letters 6:4 July/August (2013) 280–286	NA	N	Y	NA	* This article contrasts the anticipated benefits to migratory fish species as a result of fish passage structures with the reality of failed fisheries on the Atlantic coast of the USA. The authors refer to this scenario as the use of "half-way" technologies to attempt to restore diadromous migratory fish populations that have been impacted by dams. * The impetus for providing fish passage began in earnest the 1960s as a license requirement by FERC with the objective of restoring access to spawning grounds. The authors note that hydropower operators are generally required to maintain passage at defined target level, but that effectiveness is often measured simply as the ability of fish to use a fish pass. * In system with multiple dams, system-wide efficiency should evaluate the number of fish that pass the most upstream barrier to reach their destination as opposed to those that only pass the first barrier. However, this metric should be qualified by how many individuals would be expected to naturally, in a free-flowing system, have traversed all the way to the upmost barrier. * American Shad in the Connecticut River have demonstrated impacts beyond reduced recruitment as a result of restricted access to spawning grounds. The population has demonstrated a reduction in repeat spawning (likely due to delay of migration due to barriers) and decreased mean size at age (lower fecundity). * The uncertainty and controversy surrounding ecosystem valuation limits the ability to conduct objective cost-benefit analysis on dam removal.
Burdick, B., and Keading, L., R	1990	Biological merits of fish passage as part of recovery of Colorado squawfish in the upper Colorado River Basin	USA	US Fish and Wildlife Service. Colorado River Fishery Project. Grand Junction, Colorado.	squawfish (cyprinid)	NA	NA	NA	*This early 1990s report reviews the history of an experimental fishway that was explored to mitigate the impacts of water abstraction on a non-commercial fish, the Colorado Squawfish and Razorback, which is a large cyprinid. Fishway construction was to be funded by several shale gas companies. A Denil fishway was proposed based on-site conditions. *If the fishway was found to be successful at passing the target fish it would be deployed elsewhere in the Colorado river system.

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									* In 1984, a Denil fishway was proposed to meet structural needs and did not consider important biological considerations. For example, the ability of Colorado squawfish to ascend a Denil fishway was not assessed prior to installation. In 1986, the US Army Corp of Engineers undertook a feasibility study to assess passage at the site based on nine alternative passage designs that would in theory, pass the two target fish species. *The Army Corps study revealed that a vertical-slow-with-orifice fishway was the best available option, but that experiments were required to determine appropriate ladder slope, attraction flows, and water velocities. The cost of this option as estimated as $783,000 for construction with an additional $15,000 annually for maintenance. Effectiveness monitoring for three years was further costed at over $300,000. In total the project was estimated to cost $1.1 million and due to the cost was abandoned. *The report notes that at high-head barriers many passage options are not practical, and trap and truck methods are likely the most cost efficient, but with unknown effectiveness in terms of fish passage. * The report outlines when passage should be considered, and considerations for when passage may be ill-advised: "The provision of fish passage may be appropriate when it can be demonstrated that it would biologically benefit the population of endangered fishes. These situations include when (1) there is a high likelihood that squawfish will successfully spawn in a restored reach and contribute to a significant net increase in recruitment to the total adult population (i.e., when the population is spawning-habitat limited), and (2) when fish passage provides access to habitat for adult fish of a population that is "adult-habitat" limited. Fish passage may not be appropriate to provide access to habitat of a type not limiting the population." * The report also states the importance of ecological objectives: "Several important informational needs must be fulfilled prior to determining the usefulness of fish passageways in the recovery of Colorado squawfish. These are: 1)

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									Establishing concise, objective recovery goals for Colorado squawfish. These are important because they are the criteria against which the potential benefits of a proposed structure must be weighed. 2) Identifying the factors that are having the most limiting effects on the population of Colorado squawfish. 3) Acknowledging the potential problems that might occur if Colorado squawfish use a passageway and weighing these potential problems against the possible benefits to the population that passage may provide."
Castro-Santos, T., Cotel, A, and Webb, P.	2009	Fishway Evaluations for Better Bioengineering: An Integrative Approach	USA	American Fisheries Society Symposium 69:557–575,	NA	NA	NA	NA	*In an attempt to re-integrate areas of research, the authors call for a new framework to evaluate fishway performance. * The authors state that an ideal fishway would result in transparent movement of native fish through a dammed reach where movement is unfettered passing both up and downstream. To achieve such a fishway, the structure must support the following characteristics: 1) any fish wishing to enter and ascend the fishway may do so without delay, 2) fish immediately and successfully ascend the fishway upon entry, 3) passage does not result in unnatural temporal or energetic costs, and 4) no stress, disease, injury, predation, or reduced fitness occur as a result of passage. * Providing upstream passage without safe downstream passage should be considered a biological "worst-case scenario" when downstream passage is required by the species at any life stage. *The article also presents a set of criteria to define an operationally effective fishway, such that it would have an overarching objective to design, build, and operate the structure at minimal cost. The best-case scenario from an operational standpoint would be to not provide passage (that is, it is free, no maintenance, and would require no licensing).
Cheek, C.	2014	Public Service Company of New Mexico Fish Passage Facility Annual Report	USA	Navajo Nation Department of Fish and Wildlife	Razorback Sucker, Colorado Pikeminnow	NA	NA	NA	* This is an annual report that provides information on operation dates, number of fish captured and transferred upstream or returned down river at the fish pass at Public Service Company of New Mexico dam on the Colorado River. * Fish capture facility and sorting run by Navajo nation members 7 months of the year, 7 days a week. The goal is to facilitate fish passage for the

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									endangered Colorado Pikeminnow and the Razorback sucker. * Stocked endangered fish as well as natural fish fitted with pit and radio tags and demonstrated that the two species of concern were not successfully using the fish way. Significant numbers of both species were detected near the weir but were not observed in the fishway. Cause has been linked to insufficient water through the fish passage and accumulation of debris on trash screens.
Doyle, M., W., Harbor, J., M., and Stanley, E., H.	2003	Toward Policies and Decision-Making or Dam Removal	USA	Environmental Management. 31 (4): 453–465.	NA	NA	NA	NA	* This article provides guidance on how to implement a dam removal decision-making framework. This article was published in the early 2000s and was one of the earlier attempts at defining a framework to advise strategic barrier removal. * The authors argue that agencies can improve dam removal implementation with the guidance of two policies: 1) creation of a prioritization scheme to determine what is an important dam removal, and 2) establishing minimum analytical thresholds that must occur prior it decision-making. Analyses should focus on variable predictions of the positive and negative impacts of dam removal. * The authors note that by the year 2020 more than 85% of the dams in the US will approach their end of service life and decisions regarding repair, renewal, or removal will be required. Repair and renewal are the most frequently chosen option. However, social license and regulatory license conditions have changed, and repair or renewal may be prohibitively expensive given new requirements. * The potential negative impacts of dam removal are highlighted such as loss of a nutrient fixing reservoir, mortality of sedimentary reservoir species that were not salvaged (e.g., unionids), and release of sediment into downstream habitat. * An important discrepancy between agency mandate and dam removal is highlighted: " There is often an inherent contradiction between an agency's mission (which is, in part, achieved through dam operation) and dam removal. Therefore, it is not surprising that most agencies have dealt with potential removal cases

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									individually and have viewed removal as a costly economic alternative because of the apparent conflict between removal and the agency's mission." * The use of cost-benefit analysis is recommended but the authors warn that such tools are often ill-suited for dealing with uncertainty. An example of an economic analysis used during the relicensing process of the Edwards Dam is provided: "An economic analysis showed that dam removal would cost $2.7 million compared to $10 million for Edwards Dam modifications. Dam modifications would only partially mitigate environmental damages, while rendering the dam uneconomic. Based on this analysis, FERC denied the license and ordered decommissioning and removal, which occurred in 1999."
Fausch, K., D., Rieman, B., E., Dunham, J., B., Young, M., K., Peterson, D., P.	2009	Invasion versus Isolation: Trade-Offs in Managing Native Salmonids with Barriers to Upstream Movement	USA	Conservation Biology. 23 (4): 859-870	Trout	Y	N	N	*This article highlights the not-unique situation where barrier mitigation discussions to restore native fish connectivity is complicated by the presence or risk of invasion by non-native species. * The authors present a framework to assist with decision-making regarding barrier mitigation if there is a risk of negative impacts due to potential invaders. The authors focus on salmonids both native and invasive. * The framework consists of addressing four main questions: 1) are high conservation value species or populations present above the barrier (conservation value can be defined collectively as a species as evolutionary importance, its ecological function, and its distinct socio-economic value), 2) Is the population vulnerable to decline and displacement as a result of invasion by a non-native species, 3) Does the continued presence of a barrier promote the risk of extinction through genetic isolation, and 4) how is management prioritized between differing populations? * Based on the above questions trade-offs can be assessed to determine if a barrier is necessary or an impediment to target species recovery or persistence.
Federal Energy	1998	Order issuing new license to Bangor	USA	Sarah Vogel	Salmonids / Clupeidae/	Y	N	Y	* In 1990 the Milford dam FERC license expired, and the owner (Bangor Hydro) operated under an annual license until an order issuing a new license

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Regulatory Commission		Hydroelectric Company			American Eel				was granted in 1998. This FERC license was reviewed to evaluate conditions imposed on the operation of Milford Dam in the late 1990s. The order was issued by FERC under project number 2534-005 and was provided by Sarah Vogel of the University of Maine. Points of interest were extracted from the order and are provided verbatim below. The species focus at the time of the order was the conservation of Atlantic Salmon, several Clupeidae, and American Eel. * Article 406. Fishways shall be constructed, operated, and maintained to provide effective (safe, timely, and convenient) passage for the Penobscot River design populations of Atlantic salmon, American shad, alewives, and unquantified numbers of blueback herring and American eels at the Licensee's expense. The quantified design populations for each target species is 12,000 Atlantic salmon, 250,000 American shad, and up to 2.1 million alewife. * Article 407. The licensee shall install and operate permanent downstream fish passage facilities at the Milford Project. Fishways shall be maintained and operated to maximize fish passage effectiveness throughout fish migration period(s) as defined below. The downstream migration period shall be defined as April 1 to June 30 for Atlantic salmon, July 1 to December 31 for American shad and alewife, August to December 31 for blueback herring, and August 15 to November 15 (or other time periods determined when adequate information is available, and during any spring run that may occur) for American eel. Downstream facilities are to operate whenever generation occurs during the downstream migration period. The licensee shall keep the fishways in proper order and shall keep fishway areas clear of trash, logs, and material that would hinder passage. Anticipated maintenance shall be performed in sufficient time before a migratory period such that fishways can be tested and inspected and will operate effectively prior to and during the migratory periods. * Functional design and final design plans for all fishways shall be developed in consultation and cooperation with the U.S. Fish and Wildlife Service,

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									Penobscot Indian Nation, and other fishery agencies. * Downstream fishways shall consist of: (1) a downstream fishway as described in the licensee's filing dated January 12, 1990 (Response to FERC's Additional Information Request, Items 10 through 13); (2) outer trashracks with 1" clear bar spacing over the upper 12 feet of the rack (or 4" clear bar spacing on outer rack and 1" clear bar spacing on the inner trashracks with two additional entrance ports installed on the inner trashrack); (3) twin 4-foot-wide (8 feet total) weirs at the outer trashrack, capable of passing up to 280 cfs; the location of the weirs is to be west of the edge of the new generation unit (No. 2); (4) attraction flows to the downstream fishway of 280 cfs; (5) a gated bottom intake to the downstream migrant facilities for the downstream passage of American eels; and (6) a downstream migrant conduit designed so that the discharge jet does not impact on any vertical walls. * Article 408. The licensee shall install and operate permanent upstream fish passage facilities at the Milford Project. Upstream fishways shall consist of: (1) modification of the existing Denil fishway adjacent to the powerhouse as described in the licensee's filing dated January 12, 1990 (response to FERC's Additional Information Request, Items 10 through 13); (2) addition of a spillway entrance near the existing log sluice; (3) installation of additional timber baffles in the upstream end of the fishway to facilitate operation at high headpond levels;(4) fishways capable of operating at flows of up to 40,000 cfs as measured at the Eddington gaging station; (5) attraction flows for the fishways provided as follows: (a) for the existing powerhouse fishway, provide 210 cfs total for the two powerhouse entrances, and 100 cfs for the spillway entrance; (b) for the new spillway fishway, provide 100 cfs; and (6) a gated bottom intake to the downstream migrant facilities to provide for the downstream passage of American eels. * Article 409. Within 18 months after license issuance, the licensee shall file with the Commission, for approval, a plan to monitor the effectiveness of all the facilities and flows provided pursuant to Articles 407 and 408 of this license that

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									will enable the efficient and safe passage of anadromous fish migrating upstream and downstream. The results of these monitoring studies shall be submitted to the agencies listed below and shall provide a basis for recommending future structural or operational changes at the project. The monitoring plan shall include a schedule for: (1) implementation of the plan; (2) consultation with the appropriate federal and state agencies concerning the results of the monitoring; and (3) filing the results, agency comments, and licensee's response to agency comments with the Commission. * If the results of the monitoring indicate that changes in project structures or operations, including alternative flow releases, are necessary to protect fish resources, the licensee shall first consult with the agencies listed above to develop recommended measures for amelioration and then file its proposal with the Commission, for approval. The Commission reserves its authority to require the licensee to modify project structures or operations to protect and enhance aquatic resources.
Gowan, C., Stephenson, K., Shabman, L.	2006	The role of ecosystem valuation in environmental decision making: Hydropower relicensing and dam removal on the Elwha River	USA	Ecological Economics. 56: 508-523	NA	Y	NA	NA	*Gowan et al. provide a thorough history of the decision-making process and key decision points that occurred through the Elwha dam removal discussions that occurred between the mid-1980s and 1992 and the eventual initial steps toward implementation in 2001. The article focuses on key information and evaluations that occurred to inform the Elwha decision, and highlight that at no significant point did ecosystem valuation play a role in either the FERC decision nor the signing of the federal Elwha River Ecosystem and Fisheries Restoration Act (1992) that ultimately paved the way for dam removal. * The authors make the case that ecosystem valuation is often reported as a valuable tool in decision-making, but that this was not the case in the Elwha decision. The ecosystem valuation studies occurred after the decision to remove the dam was made. *The Elwha dam (and an upstream dam) was owned and operated by a private company that used the power generated at its local mill. No fish

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									passage was installed at the Elwha dam and in the early 1980s initial relicensing discussions between the owner/operator and FERC focused on marginal improvements to fish passage. FERC's decision-making process at the time of initial discussions employed a limited approach to assessing fish passage needs, such that: "Fish passage recommendations were first evaluated based on two basic criteria: (1) the probability of successfully passing different species of salmon, and (2) the costs of each passage alternative. Fish passage was not simply selected to maximize fish passage success. The final report recommended trap and haul facilities for upstream fish passage and a combination of spill and fish screens for downstream fish passage. More effective methods of passage were not recommended due to cost" * Several tribes and local resource agencies were unsupportive of the initial passage mitigation recommendations, and while dam removal was appealing the technical challenges and costs were barriers to full consideration. Local tribes were also unsupportive of proposed hatchery options. Eventually, the social movement began to grow and highlight the benefits to ecosystem restoration with dam removal. Many local agencies, tribes, and NGOs collaborated to promote and advocate for this view. * A coalition with intervener status in the FERC process conducted several studies to evaluate the potential positive impact of dam removal by estimating the ecological potential from various fish passage options, such as: potential production of juveniles based on upstream habitat suitability, life history models, and estimates of downstream mortality to estimate production. Whether the estimated restored ecological potential was worthwhile was evaluated based on an escapement goal being equal to or greater than run size necessary for self-sustaining population. Ultimately, a simple briefing memo was the major impetus for decisions based on insider accounts. The document was one page summary of sediment remediation issue and simply listed if dam removal or retention would result in good, fair or unknown consequences for salmon. * " Although FERC understood and carefully

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									analyzed the trade-offs, no effort was made to make or decide these trade-offs using a quantitative, analytical procedure. * FERC's fundamental conclusion was that the choice of a preferred alternative could not be made on a technical basis, but was instead rooted in societal values (FERC, 1991). When asked why FERC did not try to monetize ecosystem benefits to compare against costs, FERC staff recalled that staff believed such information could not resolve or reduce the conflict among firmly-entrenched positions and perhaps would make matters worse by adding more heat than light to the debate. * The Elwha case had become particularly political and the authors show that:" In 1992, President Bush senior intervened with FERC's decision to relicense the Elwha river dams. The FERC decision allowed for minor and incremental mitigation of the existing structures. The 1992 Act overturned FERC decisions to relicense and called for dam removal to support ecosystem restoration." *" Analytical efforts focused on comparative cost analysis of dam removal and fish passage and the evaluating the fishery response to fish passage/dam removal alternatives (FERC, 1997). The analyses that were instrumental in the decision making showed that constructing fish passage facilities was more expensive than simply removing the dams and that power from Edwards could be produced at a lower cost at other sources. In addition, no fish passage alternative could successfully pass 4 target species (Shortnose sturgeon, Atlantic sturgeon, Striped bass, and Rainbow smelt) and thus failing to meet the stated restoration goals"
Jager, H., I.	2006	Chutes and ladders and other games we play with rivers. Simulated effects of upstream passage on white sturgeon	USA	Can. J. Fish. Aquat. Sci. 63: 165–175	white sturgeon	N	Y	NA	* The author employed a population viability model to quantify the effects of providing volitional, upstream passage at dams on White Sturgeon (*Acipenser transmontanus*) metapopulations inhabiting a series of, simulated, long (source) and short (sink) river segments. * The simulated river systems contained variations of mixed short and long segments between barriers, and long upstream unimpeded segments. * The article outlines how traditional fish ladders built for surface-oriented jumping species are

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									ineffective and inefficiency to pass large, bottom oriented species such as sturgeon. * The author aimed to answer the questions: "1) what is the magnitude of costs and benefits of upstream passage to each population and to the metapopulation as a whole" [under each river fragmentation scenario], 2) do costs and benefits to individual populations change depending on the length of the river segments above and below the dam, and 3) how do mitigation measures intended to reduce entrainment mortality influence results?" * The results suggest that providing upstream passage in the absence of downstream passage or without exclusion (e.g., screening), was detrimental to the metapopulation. When downstream passage was "safe", then upstream passage was beneficial. * Two key recommendations are based on the results of the population viability model. 1) downstream population demographics should be understood before upstream passage is considered, 2) Anticipated risk of downstream mortality should be estimated and be considered "low" before upstream passage is provided.
Kocovsky, P., M., Ross, R., M., and Dropkin, D., S.	2009	Prioritizing removal of dams for passage of diadromous fishes on a major river system	USA	River Research and Applications 25: 107-117	Herring and American Eel	Y	N	NA	* The research presented provides a barrier prioritization tool for non-hydro barriers. The tool is based on habitat suitability index models (HSI). The tool uses the average ranks of 7 criteria related to the HSIs to evaluate priorities and focus largely on an assessment of increases in habitat quantity per barrier removed. * HSIs were used in place of true biological productivity models because target fish species have been extirpated from upstream habitats for generations and no data on potential productivity exists. Additionally, historical production estimates may not be relevant in a post-industrialized setting where flow and thermal regimes are undoubtedly altered, and land-scape level changes have altered historical habitat. * Data included in the HSI models include substrate particle size, velocity, depth, temperature, pH, dissolved oxygen, conductivity, and turbidity. As a surrogate for detailed knowledge of juvenile American Eel habitat preference, a model based on invertebrate food preferences was used. * The authors note that their HSI models are likely

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									to impart the same biases as other preference-based models such a: uncertainty regarding habitat suitability, skewed variables, and extreme value influence on the model (e.g., one barrier removal opening up > 100 km of habitat). To reduce the uncertainty of the model output and increase confidence a rank-based analysis was employed in the prioritization tool based on model results.
Miller, L., M., Heicher, D., W., Shiels, A., L., Hendricks, M., L., Sadzinski, R., A., and Lemon, D.	2010	Migratory Fish Management and Restoration Plan for the Susquehanna River Basin	USA	Susquehanna River Anadromous Fish Restoration Cooperative	Shad, herring, sturgeon, eel, striped bass	Y	Y	Y	* This 2010 document represents the Migratory Fish Management and Restoration Plan for the Susquehanna River Basin and aims to guide the Susquehanna River Anadromous Fish Restoration Cooperative. The document is meant to serve as a comprehensive watershed plan and guide migratory fish restoration and management. It is an inclusive and participatory plan that draws on stakeholder involvement to restore up and downstream passage, improve water quality and increase monitoring, as well as assist in watershed planning coordination. * The management plan provides a history of fisheries and barrier construction in the watershed and makes linkages to current population abundances for key anadromous species. * Importantly, the plan sets out clear and measurable goals and targets for the restoration of key anadromous species. Quantitative passage estimates are proposed based on an evaluation of available habitat, productivity estimates, and up and downstream cumulative mortality estimates. * An aspirational watershed goal drives the implementation of the plan. The goal of the plan is to: "Restore self-sustaining, robust, and productive stocks of migratory fish capable of producing sustainable fisheries, to the Susquehanna River Basin throughout their historic ranges in Maryland, Pennsylvania, and New York. The goals are 2 million American shad and 5 million river herring spawning upstream of the York Haven Dam. Goals for American eel and other migratory species are yet to be determined." * Plan implementation is guided by five objectives that each outline a series of tasks. The tasks describe the desired action, timeline, costs, funding sources, and recommended assessments. "A. Restore access to historic habitats for juvenile

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									and adult migratory fish. This objective calls for development of passage plans and performance measures to achieve specified minimum passage efficiency for American shad, American eels, and other migratory fish species at major basin dams. Specified minimum passage efficiencies are much higher than currently experienced at major Susquehanna River barriers. B. Maintain or improve existing migratory fish habitat. This objective focuses on essential habitat issues by inventorying blockages and assessing the impact of fish passage impediments through active involvement of SRAFRC in watershed project reviews while supporting monitoring and improving water quality. C. Enhance migratory fish spawning stock biomass and maximize juvenile recruitment through natural and/or artificial means. This objective includes a variety of tasks designed to directly or indirectly improve migratory fish stocks in the Susquehanna River. Tasks focus on improving current techniques for artificial augmentation of American shad stocks, developing new techniques for augmenting river herring and eel populations, restoring non-Alosine migratory fish, improving instream migration, spawning and rearing habitat, and maintaining existing regulatory framework restricting harvest of migratory fish. D. Evaluate the migratory fish restoration effort and adjust programs or processes as needed. This objective stresses the importance of data dissemination and analysis. Tasks included in this section will continue to collect baseline data essential to monitor restoration progress while researching and experimenting with technologies to improve survival, reproduction and spawning biomass. E. Ensure cooperation among all restoration partners while generating support for migratory fish restoration among the general public and potential funding sources. This objective stresses the importance of a watershed approach to restoration and emphasizes the need to include coastal states and ocean waters."

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Milt, A., W., Diebel, M., W., Doran, P., J., Ferris, M., C., Herbert, M. Khoury, M., L., Moody, A., T., Neeson, T., M., Ross, J., Treska, T., O'Hanley, J., R., Walter, L., Wangen, S., R., Yacobson, E., and McIntyre, P., B.	2018	Minimizing opportunity costs to aquatic connectivity restoration while controlling an invasive species	USA	Conservation Biology. 32 (4): 894-904	NA	NA	NA	NA	* The researchers quantified the trade-offs between providing passage for 37 desirable species to meet watershed objectives, against the detrimental impact that passage would be created based on invasive species success in newly accessible habitats. The goal was to identify priority barriers for removal or mitigation in the Great Lakes basin. * Migratory fish restoration in the Great Lakes basin and control of the invasive Sea Lamprey create opposing management needs. Ideally, management options would maximize and prioritize barrier removal for migratory species benefit while limiting habitat available to Sea Lamprey. * The authors quantified tradeoffs by first "assessing the degree to which limiting access for Sea Lamprey to spawning habitat affects the ability to restore access for 37 desirable species. Second, we evaluated whether such opportunity costs can be overcome by paying a premium for barrier removals that avoid sea lamprey habitats. We used a basin-wide barrier-removal optimization model that maximized accessibility-weighted habitat for individual desirable species while limiting access for Sea Lamprey." * Habitat use was estimated as a function of barrier passability both up and downstream and assuming species fall into one of three guilds based on adult sustained swimming speed.
Roy, S.G., Uchida, E., de Souza, S.P., Blachly, B., Fox, E., Gardner, K., Gold, A.J., Jansujwicz, J., Klein, S., McGreavy, B., Mo, W., Smith, S.M.C., Vogler, E., Wilson, K., Zydlewski, J., & Hart, D.	2018	A multiscale approach to balance trade-offs among dam infrastructure, river restoration, and cost	USA	PNAS. 115 (47): 12069-12074	NA	Y	Y	N	* This article proposes an approach to inform dam decision-making (creation, remediation, removal) based on the quantification of complex trade-offs. The approach is demonstrated using a model system, the Penobscot River, in New England, USA. * On the Penobscot River, migratory fish populations have rebounded due to barrier mitigation on a large scale, and these benefits came at only minimal impact on hydropower generation. This success occurred because of strategic mitigation planning and implementation: two large main stem dams were removed but capacity was increased on tributaries, and fishways were installed on a wide scale. *In NE, only 3% of the river systems are unobstructed for migratory anadromous species. *The authors use production possibility frontier

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									(PPF) coupled with a multi-objective genetic algorithm (MOGA) to quantify the ecological, economic, and social trade-offs associated with dam decisions in NE. * The results demonstrate with the removal of dams that do not meaningfully contribute to overall hydro production, 38% of river habitat could be restored. The model estimates increase in biomass as a proportion of hydropower loss: where power loss is high and biomass increases are small, dam removal is not highly prioritized. * The authors argue that dam decisions are more efficient when they are strategically coordinated across dams at a watershed scale. For example, the authors note: "we set a hypothetical goal of restoring biomass to half of its estimated maximum capacity (Fig. 1G). According to our results, it is possible to achieve this goal in NE with a loss of 16 megawatts and $1.6 billion in estimated dam removal costs by the focused removal of dams from specific watersheds. In contrast, if we apportion restoration evenly across all NE sub watersheds (Fig. 1A) with at least partial sea-run fish access, there would be a loss of 632 megawatts and $2.48 billion in estimated dam removal costs." *In terms of the economic consequences of dam decisions, it was estimated that removal costs are "on average 50% less than fish passage installation and 82% less than new turbine installation".
Schilt, C., R	2007	Developing fish passage and protection at hydropower dams	USA	Applied Animal Behaviour Science. 104: 295-325	Salmonids	N	N	N	* This article outlines the rational for providing fish passage based on known and suspected impacts of barriers and reservoirs, especially to obligate migratory species such as salmon. * An evaluation of impacts to adult and juvenile salmon due to passage (up and downstream) is provided. The paper also discusses novel technologies to assist with downstream migration such as light and sound barriers. * The authors call for strategically improving fish passage to increase the number of fish passed per amount of water diverted for power in order to reduce the conflict between human and water needs and fish passage. *The article does not consider decision-making options for determining when or where to place passage but suggests that if mortality or delay is

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									observed during passage at a fishway or barrier, then more mitigation is required.
Sharma, S., Waldman, J., Afshari, S., and Fekete, B.	2019	Status, trends and significance of American hydropower in the changing energy landscape	USA	Renewable and Sustainable Energy Reviews. 101: 112-122.	NA	NA	NA	NA	* An energy focused article, the authors aimed to estimate the contribution of hydropower to total energy production in the USA, identifying key hydropower producing regions. * Importantly, the authors suggest that despite continually investments and retrofit of hydropower faculties since 2000, the mean contribution of hydropower to total US energy production is less than 10%. They suggest that the reservoir/dam model may not be an efficient energy source in modern America. * The global perception that hydropower is a large contributor to the global energy mix is probably based on its contribution of 1096GW in 2016 (16.4%) and because of its attractive feature of being able to instantly load balance based on demand. * Given the predicted impact of climate change, it has been suggested that over the next 20-50 years up to 74% of the global "usable capacity of hydropower" could be lost without significant mitigation and operational changes. * " At the national level [USA], small hydropower dams are the most abundant ones, comprising almost 65% of all hydropower facilities (total N=2320) but generating a mere 3.5% of the total nameplate capacity. Very large hydropower dams are the least numerous (just under 2% of the total facilities) but have the capacity to generate up to 54% of the total hydro-energy". * A discussion of the potential impacts of small hydropower barriers vs large power facilities in China is discussed. *The authors also review the status of high hazard dams in the US and estimate mitigation costs. They note barrier removal is most often the most economical option. The authors also point out that hydropower facility maximum capacity is often not reached and true operational capacity was estimated as low as 45% for all US facilities examined in 2017. * The authors suggest the Integrative Dam Assessment Modelling tool can assist with integration of multiple perspectives including

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									political, biological, physical, and socio-economic, to inform dam decision-making (on a site-by-site basis).
Sweka, J., A., Eyler, S., and Millard, M., J	2014	An Egg-Per-Recruit Model to Evaluate the Effects of Upstream Transport and Downstream Passage Mortality of American Eel in the Susquehanna River	USA	North American Journal of Fisheries Management. 34: 764-773	American Eel	Y	Y	NA	*This article employs an egg per recruit model for American Eel to demonstrate reproductive output from a river considering cumulative effect of decreased survival with subsequent dams on Susquehanna River, USA. * Cumulative downstream survival must be much greater than 33% for upstream passage to be beneficial, otherwise upstream passage is likely to result in a population sink. * American Eels restricted to areas below dams live in higher densities, which is predicted to result in reduced survival, modified sex ratios, and reduced growth rates. However, those that ascend dams face higher mortality and injury rates when migrating downstream in the absence of modified downstream passage. * Cumulative eel downstream mortality can be as high as 37-82% based on dam specific passage mortality and number of dams to cross. * A numerical EPR model was developed that allowed the number of recruits who become female to increase as passage increased (because more females are predicted at upstream, lower density habitats). Therefore, the greater the rate of passage the higher the total production (eggs per recruit) of the river (assuming 100% downstream survival). * The authors assumed fecundity is higher and lower rates of predation in upper tributaries compared to downstream habitats. *The model also assumes that sex of the eel has not differentiated by 2 years old (115m) when arrive at first dam in the system and that 80-100% of passed eels would become female in upper tributaries. *Compared results of EPR if all dams made passable, no dams made passable, and if all dams were removed. * When downstream mortality at each facility was > 20%, EPR was higher when upstream passage was limited. * At the break-even threshold, expect EPR with passage to be greater than base-EPR (e.g., do nothing scenario) approximately 50% of the time.

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US Department of Energy	2016	Hydropower Vision: A new chapter for American's 1st Renewable Electricity Sources	USA	U.S. Department of Energy Office of Scientific and Technical Information 407 pp P.O. Box 62 Oak Ridge	NA	NA	NA	NA	*This strategic plan was prepared by the US Department of Energy and guides the future of hydropower development and maintenance in the USA (post 2015). The document speaks very little to fish passage, and only for "key species". * The report calls for the establishment of environmental objectives against which to measure project success and effectiveness. The report gives qualitative examples and users are directed to develop site-specific measures (that is, not a holistic approach). * Hydropower development is suggested to be sited, build, and operated to balance ecological considerations with physical processes within the system. *Several environmental specific actions are identified in the strategic plan, including: "ACTION 4.1.2: Enhance Environmental Performance of New and Existing Hydropower Technologies. ACTION 4.1.2.1: Develop metrics, monitoring, and measurement methodologies for environmental stressors. ACTION 4.1.2.2: Develop biologically-based design and evaluation techniques for hydropower components and associated water control facilities. Action 4.1.2.3 Apply environmental performance findings within an adaptive management process to prompt modifications to given hydropower technology. Action 4.1.2.4 - Compare environmental metrics before and after upgrades, new environmental requirements, or deployments at select example facilities to validate and communicate environmental performance improvements. Action 4.1.2.5 - Ensure that enhancing environmental performance is addressed within hydropower fleet modernization efforts."
Wisconsin Department of Natural Resources	2017	Fish Passage at Dams Strategic Analysis	USA	Wisconsin Department of Natural Resources	NA	N	N	N	* This document was created to provide an overview and strategic analysis of the issues that impact fish passage decision-making and to inform future policy development. It highlights the important environmental and societal issues related to fish passage management and outlines potential policy approaches.

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									* Estimating the carrying capacity of habitats, and availability of suitable habitat up and downstream of barriers is important information required to determine the need for fish passage. The extent of up and downstream habitat considered at a specific barrier is typically influenced by professional judgement of assume habitat needs for life stages of target fish species. * This document (strategic analysis) was deemed necessary in 2015 prior to the development of a policy to be used when evaluating proposed fish passage projects. * The document outlines seven potential policy alternatives related to fish passage options at barriers and provides a broad overview of what each policy alternative would look like and potential concerns (e.g., safety concerns and mitigation of increase invasive species movement). * The seven identified policy alternatives are: 1) Free movement of aquatic species at all dams, 2) No new fish passage at dams, 3) No fish passage at all dams (remove existing fish pass structures), 4) Fish passage only where no AIS are present, 5) Fish passage where AIS are present, but only when BMPs are used, 6) Economically drive fish passage decisions, and 7) Ecologically driven fish passage decisions. * The document states that any policy alternative chosen should develop a priori goals and objectives to ensure that project outcomes are met, and monitoring is used to assess progress toward outcomes and to identify when mitigation is required. * Under policy options that provide some measure of fish passage habitat suitability should be considered to ensure passage options will meet desired ecological objectives: "An assessment should consider water quality and trophic structure above a dam, to ensure that it will support the development of viable populations for the target species."
Zweifel, J., C.	2016	A landscape-scale watershed assessment method to support fish passage restoration	USA	Oregon State University. MSc.	Salmon	Y	Y	N	* This 2016 graduate thesis outlines the results of a landscape-scale assessment of habitat indicators to be used to inform prioritization of watersheds for barrier removal in the state of Washington. * The Fish Barrier Removal Board of Washington

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		in Puget Sound, Washington State: An analysis for the Fish Barrier Removal Board							was asked to develop a strategy to prioritize barrier removal in the state that would have the largest benefit to salmon and steelhead recovery. The strategy should include the most efficient and cost-effective recommendations that are practical. * Two indicators were used to inform prioritization: potential for steelhead rearing and impervious land cover. These two indicators correspond to habitat suitability and anthropogenic disturbance. * The author notes that: "The most common assessment criteria used in many of these prioritization methods include the barrier's position in the stream network, severity of barrier, amount and quality of habitat, estimated cost of the barrier correction, and species use. Most prioritization formulas support the integration of additional criteria or the use of coefficients to weight specific variables to help formulate an output that aligns with project-specific goals." * The Puget Sound Salmon Recovery Plan that outlines the goals and objectives to achieve regional recovery planning (Puget Sound Partnership, 2005) and also provides specific numerical recovery targets and criteria for abundance and escapement goals for each watershed. * The author notes that the limited availability of data necessitated the use of proxy indicators: "Due to the incompleteness and limited availability of population data, and the restriction of migratory species' spatial distribution imposed by instream barriers, an estimate of habitat suitability was used as a surrogate for actual salmon and steelhead occurrence data. The use of Intrinsic Potential models is a common method for conducting large-scale valuations of habitat. Because these geomorphic and hydrologic characteristics are not significantly affected by anthropogenic disturbances, IP is considered a reliable indicator of a stream's historic condition as well as a predictor of its potential condition if anthropogenic factors were removed"