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Fish Passage and Hydropower: Investigating Resource Agency Decision-making During the FERC Hydropower Relicensing Process

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FISH PASSAGE AND HYDROPOWER: INVESTIGATING RESOURCE AGENCY DECISION-MAKING DURING THE FERC HYDROPOWER RELICENSING PROCESS

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An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
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Hydropower dams represent a significant challenge for the successful migration of sea-run fish, many species of which are in decline. Most hydropower dams in the United States are regulated by the Federal Energy Regulatory Commission (FERC), an independent federal agency responsible for granting 30 to 50-year licenses to projects for their continued operation. Licenses typically include conditions for the conservation of sea-run fish such as fish passage construction, operational changes, monitoring of effectiveness, and other mitigative conditions. While FERC remains the primary authority in licensing, the current regulatory framework stipulates input from other federal and state resource and regulatory agencies, many working from differing timeframes, varying levels of authority, and within the bounds of a complex legal system.

Outside of the relicensing process, modifications and improvements are not required unless prescribed in the original license or prompted by legal action (e.g., the listing of new species under the ESA). In effect, the relicensing process presents the most effective opportunity for agencies to influence dam operations. Due to accelerated construction of hydropower dams in the 1980s, many of the projects in Maine will require relicensing within the next decade requiring input from an array of federal and state agencies. When negotiating hydropower operations, agencies must make timely decisions and

examine tradeoffs based on their respective and often competing authorities, values, and objectives. Using the Kennebec and Penobscot Rivers in Maine as a model system, the overall goal of this research is to examine the hydropower relicensing process to: 1) identify and describe the role and authority of resource agencies during dam relicensing, 2) determine the factors that may affect the design and implementation of fish passage measures, and 3) highlight management and policy implications that may be used to inform fish passage decisions and future relicensing efforts. This research provides the historical context for fish passage in the study area and describes hydropower regulation.

The first chapter uses content analysis of relicensing documents readily available on the Federal Energy Regulatory Commission (FERC) eLibrary to identify the main factors that influence fish passage decision-making and describe patterns in agency engagement during relicensing. Our results indicate an overall increase in concern for fish passage over time with mitigation measures focused almost exclusively on Atlantic salmon and American eel. Agency engagement and the use of regulatory authority increased after the 1900s, especially with regards to the use of Water Quality Certification conditions as a tool for addressing fish passage. Overall, hydropower projects were found to differ along a spatial gradient with coastal projects correlated strongly to fish passage language and input from the Maine Department of Marine Resources (MDMR), United States Fish and Wildlife Service (USFWS), and National Oceanic and Atmospheric Administration (NOAA) and inland projects to input from the Maine Department of Inland Fisheries and Wildlife (MDIFW). Despite stated interest in basin-scale planning, policies in support of it, and continued improvement, implementation has been slow at best. Our results suggest there remain significant opportunities to spatially integrate the FERC process.

The second chapter investigates the concept of “best available science” (BAS) as it applies to the relicensing decision process. Agency regulators are tasked with using the BAS to make informed decisions about hydropower operations and management. Although embraced as the standard, best available science is not well-defined and is inconsistently applied. Citation analysis and an online survey

of regulatory and resource agency staff were used to identify the informational sources used in relicensing and assess agency perceptions of BAS. Analysis of relicensing documents (n=62) demonstrates that FERC and licensee documents (i.e., documents produced by the individual or organization that was granted the license) are highly similar in citation composition. NOAA reports typically cite more sources and are three times more likely to cite peer-reviewed literature than FERC and licensee documents. Survey data reveals that federal and state agency respondents (n=49) rate peer-reviewed literature highly in terms of BAS, followed by university (e.g., theses), agency (e.g., agency grey literature), and expert sources (e.g., guidance from experts), while industry (e.g., consultant reports) and community (e.g., comments and personal interactions) sources rate poorly. Overall, there is low agreement among respondents with regards to BAS rankings of informational sources. The reported differences in information use may be linked to disparities in access to certain sources, particularly peer-reviewed literature. A common concern expressed by agency staff is the lack of applied technical information for all aspects of dam operations.

One such disparity relates to the difficulty in assessing downstream passage for out-migrating juvenile fish. The final chapter addresses this knowledge gap by describing the development of a novel buoyancy conversion (BC) tag that may be used to facilitate fish recapture for passage assessments. The BC tag uses low-cost materials, does not significantly hinder fish movement, and has a delayed deployment. This chapter provides a detailed description of the BC tag and describes the process used to optimize the tag for a range of fish sizes, specifically for juvenile river herring. This work is intended for the public domain and is meant to be highly adaptable for use with many fish species and life stages.

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LIST OF ACRONYMS AND ABBREVIATIONS

ALP	Alternative Licensing Process
BA	biological assessment
BAS	best available science
BIOP	Biological Opinion
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
EA	environmental assessment
EFH	essential fish habitat
EIS	environmental impact statement
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
FPA	Federal Power Act
FWCA	Fish and Wildlife Coordination Act
ILP	Integrated Licensing Process
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MDEP	Maine Department of Environmental Protection
MDMR	Maine Department of Marine Resources
MDIFW	Maine Department of Inland Fisheries and Wildlife
NEPA	National Environmental Policy Act
NGO	nongovernmental organization
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent

PIN	Penobscot Indian Nation
PAD	preliminary application document
TLP	Traditional Licensing Process
USFWS	U.S. Fish and Wildlife Service
WQC	Water Quality Certification

CHAPTER 1

FISH PASSAGE DECISION-MAKING DURING HYDROPOWER RELICENSING IN THE KENNEBEC AND PENOBSCOT RIVERS, MAINE

Abstract

Hydropower dams represent a significant challenge for the successful migration of sea-run fish, many species of which are in decline. The Federal Energy Regulatory Commission (FERC) regulates most hydropower dams and grants 30 to 50-year licenses to projects which typically include conditions for the conservation of sea-run. FERC is the primary authority in licensing, however over time, the process has been expanded to require input from other federal and state resource and regulatory agencies. When negotiating hydropower operations, agencies must make timely decisions and examine tradeoffs based on their respective and often competing authorities, values, and objectives.

Using the Kennebec and Penobscot Rivers as a model system, we sought to identify the main factors that influence fish passage decisions-making and describe patterns of agency engagement in licensing. Our results indicate an overall increase in concern for fish passage over time with mitigation measures focused almost exclusively on Atlantic salmon (*Salmo salar*) and American eel (*Anguilla rostrata*). Agency engagement and the use of regulatory authority increased after the 1990s resulting in increased complexity. Overall, hydropower projects were found to differ in management along a spatial gradient. Coastal projects correlated strongly to fish passage language and input from the Maine Department of Marine Resources (MDMR), U.S. Fish and Wildlife Service (USFWS), and National Oceanic and Atmospheric Administration (NOAA) and inland projects to input from MDIFW. Despite stated interest in basin-scale planning, policies in support of it, and continued improvement, implementation has been slow at best. Our results suggest there remain significant opportunities to spatially integrate the FERC process.

Introduction

Hydropower dams are considered a clean source of domestic renewable energy and important in lowering our nation's dependence on fossil fuels (Dincer and Acar, 2015). Although dams provide important benefits, they alter and fragment riverine habitat in ways that can be detrimental to sea-run fish, many species of which are in decline (Fuller et al., 2015; Hall et al., 2011). Notable declines in culturally and economically important species have led to more intense scrutiny of hydropower dam operations. A complex regulatory framework is in place to license hydropower dams and address energy, recreation, and environmental concerns. Nonfederal hydropower dams (*"projects"* hereafter) in the US are regulated by the Federal Energy Regulatory Commission (FERC), an independent federal agency which grants licenses to hydropower projects that specify the conditions for project operations (16 U.S.C. Ch. 12). Licenses last 30 to 50-years and must be relicensed periodically. They typically include conditions for the conservation of sea-run fish including the construction of fish passage facilities, changes to operations, monitoring of effectiveness, and other mitigative conditions.

While FERC remains the primary authority in relicensing, the current relicensing framework stipulates input from other federal and state resource and regulatory agencies. These agencies invoke a suite of regulatory authorities and have the ability to affect license conditions (Richardson, 2000). When negotiating changes to hydropower operations during relicensing, agencies must make timely decisions based on their often competing authorities, values, and objectives (Richardson, 2000). Outside of the relicensing process, modifications and improvements are not required unless prescribed in the original license or prompted by legal action (e.g., the listing of new species under the ESA). In effect, the relicensing process presents the most effective opportunity for agencies to influence dam operations while considering human uses and ecological impacts (Kosnik, 2010).

In the next two decades, more than half of all active FERC-regulated projects in the nation will require relicensing (Curtis and Buchanan, 2018). This demanding forecast will necessitate increased participation from agencies and has led to pressure for a more streamlined decision-making process (Berube et al. 2002). An understanding of the factors that influence agency decision-making is important for navigating relicensing and informing future negotiations. The Kennebec and Penobscot River watersheds in Maine provide an exemplary case for investigating fish passage decision-making in this context.

The Kennebec and Penobscot Rivers drain more than 40 percent of the state by area and contribute substantially to Maine's energy profile. In 2018, 31 percent of net electricity generation came from hydropower, the most per capita of any state East of the Mississippi (EIS, Profile Analysis, 2019). Additionally, Maine ranks the fifth highest in the nation for the number of hydropower projects requiring relicensing in the next two decades (n = 40; Curtis and Buchanan, 2018). Projects in these watersheds exhibit a range of diverse characteristics (Table 1.1). They include small and large hydropower dams as well as non-generating storage facilities. Some occupy mainstem rivers close to the watershed mouth while others occupy small tributaries farther inland. A variety of fish species exist within project boundaries and fish passage measures that are negotiated and enforced vary from project to project. These rivers have been the site of notable conservation efforts and basin-scale planning initiatives. The diversity in the Kennebec and Penobscot River watersheds makes insight into agency decision-making transferable to other projects nationwide that exhibit similar characteristics.

Table 1.1. Hydropower project characteristics. General characteristics for hydropower projects in the Kennebec and Penobscot River watersheds including: project name and number of dams (if more than one); licensing process and year of current license; river where facility is located; authorized capacity (GW); mode-of-operation (e.g., run of river, storage, or combination); reservoir storage volume (million m3); dam height (m); number of documents in project docket; and the proportion of documents mentioning fish passage.

Project	Code	Process	Lic year	River	Auth cap (GW)	Mode of operation	Storage volume (mil m^3)	Height (m)	Project doc	FP Docs
Abenaki	ABE	ALP	2003	K	18.8	ROR	0.6	7.6	513	9.6%
American Tissue	AMT	TLP	1979*	K	1	ROR	0.1	7.3	775	12.5%
Anson	ANS	ALP	2003	K	9	ROR	7.2	11.0	617	8.9%
Automatic #4	AUT	TLP	1999	K	0.8	ROR	1.1	9.9	402	1.7%
Benton Falls	BEN	TLP	1984	K	4.33	ROR	1.2	8.2	604	22.5%
Brassua	BRA	ILP	1977*	K	4.18	STOR	254.1	15.2	1204	2.6%
Burnham	BUR	TLP	2004	K	1.05	COM	2.3	9.8	559	25.2%
Eustis	EUS	TLP	1996	K	0.25	ROR	0.7	5.2	287	2.4%
Flagstaff	FLA	TLP	2004	K	0	STOR	339.8	13.7	949	1.0%
Great Lakes Hyd (9)	GLH	TLP	2004	P	0	STOR	33.6	7.9	1144	1.2%
Great Works	GRW	TLP	1963	P	7.655	ROR	NA	4.9	656	10.5%
Howland	HOW	TLP	1980	P	1.875	ROR	NA	5.2	827	15.5%
Hydro Kennebec	HYK	TLP	1986	K	15.433	ROR	4.8	10.7	1099	12.3%
Indian Pond	INP	TLP	2004	K	76.4	STOR	96.2	53.3	1268	1.4%
Lockwood	LOC	TLP	2005	K	6.915	ROR	0.7	5.2	897	18.5%
Lowell Tannery	LTA	TLP	1983*	P	1	ROR	0.8	8.2	369	4.3%
Mattaceunk	MAT	TLP	1988*	P	19.2	ROR	25.9	13.7	1034	9.3%
Medway	MED	TLP	1999	P	3.44	ROR	1.9	10.8	653	11.3%
Messalonskee (3)	MES	TLP	1999	K	5.9	ROR	0.7	6.6	1059	0.8%
Milford (2)	MIL	TLP	1998	P	8	ROR	2.8	10.4	1260	14.7%
Moosehead Lake (2)	MOH	TLP	1997	K	0	STOR	1332.2	6.9	1037	1.0%
Orono	ORO	TLP	2005	P	6.518	ROR	1.6	4.6	854	22.4%
Penobscot Mills (5)	PEN	TLP	1996	P	70.81	COM	109.4	10.6	2355	0.5%
Ripogenus	RIP	TLP	1996	P	37.53	STOR	848.6	25.3	1633	0.6%
Shawmut (2)	SHA	ILP	1981*	K	8.74	ROR	6.2	7.9	688	12.2%
Stillwater	STI	TLP	1998	P	4.179	ROR	2.4	7.6	1109	16.8%
Veazie	VEZ	TLP	1998	P	8.4	ROR	NA	6.1	1127	11.8%
Wenfield	WEN	TLP	1984*	P	13	ROR	14.2	4.6	817	14.3%
Weston	WES	TLP	1997	K	15.98	ROR	22.9	11.6	1156	6.8%
Williams	WIL	ILP	2017	K	13	STOR	5.6	13.7	174	12.6%
Wyman	WYM	TLP	1997	K	83.7	STOR	257.7	47.2	1242	1.9%

*Indicates projects that have submitted Notice of Intent documentation (NOI); are currently involved in the relicensing process (Lowell Tannery, Mattaceunk, Brassau, Shawmut, West Enfield), or have completed relicensing (American Tissue, 2019)

This is especially important given the expected increase in workload related to the demanding relicensing forecast. Basin-scale management has been identified as a way to reduce this complexity by addressing objectives at multiple dams simultaneously (Curtis and Buchanan, 2018). FERC has issued a policy statement (2017a) in support of coordinating license expiration dates for projects in the same river basin in order to synchronize relicensing decision-making. Similarly, environmental assessments required by the National Environmental Policy Act (NEPA), require that the cumulative impacts of multiple projects be assessed during relicensing. While basin-scale management is advocated, implementation remains inconsistent at individual projects.

Lessons learned from past decisions will allow us to track and gauge responsiveness to the changing management paradigms (i.e., calls for more integrative basin-scale planning) and may help inform future negotiations and alleviate some process complexity. This requires knowledge of the primary agency stakeholders involved in the relicensing process, an understanding of the factors that influence agency decision-making, and knowledge of the insight on the opportunities and challenges facing the design and implementation of basin-scale hydropower planning. This paper sets the groundwork by introducing the history of fish passage in the study area and describing hydropower regulation. Methods are presented for using content analysis of archived relicensing documents to extract and analyze textual data relevant to fish passage decision-making. Finally, guidance is given regarding challenges to basin-scale hydropower management that may augment agency decision-making in the future.

Figure 1.1. Hydropower projects in the Kennebec and Penobscot River watersheds, Maine.

Hydropower Dams and Fish Passage

The Kennebec and Penobscot Rivers have been of high economic importance for the transport of timber and for paper production since the nineteenth century (Gibson, 2017). These activities were predicated on the construction of dams for water control and hydropower for industrial mills. While river uses have changed over time, hydropower dams still play an important role in Maine's economy, contributing 450 thousand megawatts of power (Table 1.1). Dams in the Kennebec and Penobscot Rivers include 31 actively licensed projects (Figure 1.1). These represent significant barriers to the upstream and downstream migration of sea-run fish that are important to commercial and recreational fisheries in the area (Hall et al., 2011; Linnansaari et al., 2015).

Sea-run fish must undertake long-distance migrations and cross the ocean-freshwater boundary in order to complete their life history. Fragmentation alters and reduces access to essential fish habitat, limiting spawning and rearing grounds (Hall et al., 2011) and artificially influences fish assemblages (Kiraly et al., 2014; Watson et al., 2018). Hydropower dams have been linked to fish mortality and injury particularly associated with turbine passage (Maynard et al., 2018a; Olden, 2015; Pracheil et al., 2016). Furthermore, delays incurred at dams are energetically taxing and may negatively impact survival (Izzo et al., 2016; Nyqvist et al., 2017). Damming has specifically been identified as a leading cause for the substantial population declines in the Kennebec and Penobscot Rivers (Bunt et al., 2011; Limburg and Waldman, 2009).

There are 11 sea-run species native to the Kennebec and Penobscot Rivers. Most notable is the Atlantic salmon (*Salmo salar*), of which the Gulf of Maine Distinct Population Segment (GOM DPS) is listed as endangered under the ESA (65 FR 69459). Atlantic salmon in the study area once supported multi-million dollar recreational and commercial fisheries and were essential to subsistence fishing by the Penobscot Indian Nation (PIN). While the Penobscot River continues to host the largest run of Atlantic salmon in the state, returns remain low (NASCO, 2019) prompting intense restoration efforts.

The similarly endangered shortnose sturgeon (*Acipenser brevirostrum*) and the threatened GOM DPS of Atlantic sturgeon (*A. oxyrinchus oxyrinchus*) are carefully managed for handling and rescue, but not passage upstream (78 FR 69310; 32 FR 4001). American eel (*Anguilla rostrata*), which supports a lucrative fishery, has experienced declines that have prompted consideration for listing under the ESA twice in 2007 and 2015. To a lesser extent, unlisted species in decline such as American shad (*Alosa sapidissima*), blueback herring (*A. aestivalis*), and alewife (*A. pseudoharengus*) have been identified for conservation action by resource agencies. Other sea-run fish in the Kennebec and Penobscot Rivers (striped bass (*Morone saxatilis*), rainbow smelt (*Osmerus mordax*), Atlantic tomcod (*Microgadus tomcod*), and sea lamprey (*Petromyzon marinus*)) receive very little management attention. Conversely, management has sporadically included provisions for exotic and invasive sport fish such as largemouth and smallmouth bass (*Micropterus salmoides; M. dolomieu*). This is illustrated in the Stillwater license (1998), which specifies the project flows required to sustain smallmouth bass spawning, rearing, and adult habitat.

Fish passage may encompass a wide range of *"passive," "active,"* or *"guidance-based"* solutions. Passive solutions include permanent or interim structures that require little human involvement, besides routine upkeep, for fish to pass dams. These may include different types of fishways and bypasses such as the vertical slot fishway at the West Enfield Project and the nature-like bypass at the Howland Project (Figure 1.1). Active solutions require focused human labor to move fish around dams. These may include trap and truck methods, fish lifts, etc. such as the state-of-the-art fish lift at the Milford Project and trapping fish and moving them upstream at the Lockwood Project (Figure 1.1). In addition to passive and active solutions, the use of exclusionary devices and sensory stimuli to guide fish away from turbines (e.g., lights, turbulence, bubble curtains, and electric fields) can be used (Schilt, 2006). It may be noted that fish passage requirements are usually restricted to certain times of year, species, and life-stages. Passage designed for one species is rarely uniformly beneficial to all, resulting in inequitable passage accessibility (Roscoe and Hinch, 2010; Noonan et al., 2012) and changes in demography and fitness (Anderson et al., 2006; Maynard et al., 2018). Additionally, connectivity requires both upstream and downstream passage to be effective for all life history stages (Calles and Greenberg, 2009; Silva et al., 2018).

In addition to fish passage, ancillary mitigation measures may be adopted in place of physical requirements. In-lieu funding may consist of fees that generally fund conservation efforts and environmental studies in the watershed in place of immediate fish passage construction. Stocking of hatchery-reared fish is another mitigative measure to supplement native fish populations, address the recovery of endangered species, and fulfill trust responsibilities (USFWS 2018). However, it is widely accepted that hatchery-reared fish experience lower survival than their wild counterparts and show differences in behavior, morphology, genetics, and physiology (Maynard et al., 1995; Brown et al., 2003).

Beyond fish passage and mitigative measures, assessment of tradeoffs has led to complete dam removals (Stanley and Doyle, 2003). The most notable conservation-driven removal was of the Edwards Dam on the Kennebec River in 1997. In relicensing proceedings, FERC found that the economic value of the dam did not compensate for the environmental liabilities it incurred, particularly for fish passage (Opperman et al., 2011; Wildman, 2013). This was the first federally-ordered dam removal against the wishes of a licensee in US history. This action paved the way for other improvements to fish passage including the removal of the Veazie and Great Works Dams on the Penobscot River in 2012 and 2013 (Figure 1.1). These were the result of a coordinated negotiation, endorsed by FERC, to balance fish restoration and energy generation. The project included conservation organizations, state agencies, USFWS, tribal entities, and multiple licensees (Opperman et al., 2011).

Regulation of Hydropower Projects and The FERC Relicensing Process

Like all FERC regulated hydropower projects nationwide, dams in the Kennebec and Penobscot Rivers follow established procedural pathways for licensing. The licensing process follows one of three procedural pathways that vary in the level of stakeholder involvement: *i*) the Traditional Licensing Process (TLP), *ii*) Alternative Licensing Process (ALP), and *iii*) Integrated Licensing Process (ILP). Until 2005, the TLP was the default process and involves little to no early FERC oversight and favors stakeholder involvement later in the process (18 C.F.R. § 4.38). Participation by FERC and other stakeholders does not occur until after a license application is filed, generally two years prior to its expiration. In contrast, the ALP favors self-driven stakeholder collaboration with some early FERC involvement (18 C.F.R. § 4.34(i)). It allows environmental review and pre-filing consultation to occur in tandem but does not exhibit a highly rigid regulatory schedule.

The ILP became the default process in 2005 and is designed to streamline the relicensing process. It includes FERC oversight and stakeholder involvement upon the submission of a Notice of Intent (NOI) to file a license application (no more than five and a half years prior to expiration) and enforces predictable timeframes (18 C.F.R. Part 5). Despite being developed to standardize relicensing, concerns exist over this process due to the amount of early stakeholder effort required and the tight time frames imposed for decisions (Swinger and Grant, 2004).

Hydropower relicensing remains complex and demands have been made to further simplify the process and reduce licensing timeframes as illustrated by the America's Water Infrastructure Act (2018) aimed at establishing an expedited process for issuing and amending licenses. Today, the TLP may be requested for projects with relatively simple concerns and few study needs while the ALP may be requested for smaller projects that demonstrate stakeholder consensus regarding the concerns and objectives at the projects. Regardless of the procedural pathway taken, opportunity exists for diverse stakeholder involvement and the relicensing process is especially reliant on input from state and federal resource and regulatory agencies.

In the Kennebec and Penobscot Rivers, the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NOAA) are the primary federal resource agencies that participate in relicensing activities. Broadly, NOAA is responsible for managing sea-run fish while USFWS is responsible for managing terrestrial and freshwater wildlife. Additionally, USFWS administers the National Fish Hatchery System which supports two Atlantic salmon hatcheries in Maine. Maine is unique in that it has three state agencies devoted to managing Maine’s diverse resources. The Maine Department of Marine Resources (MDMR) manages sea-run fish. The Maine Department of Inland Fisheries and Wildlife (MDIFW) manages freshwater fish such as trout (*Salvelinus sp*), whitefish (*Coregoninae sp*), and bass (*Micropterus sp*) and maintain a general focus on recreational angling, stocking activities, and the prevention of invasive species. The Maine Department of Environmental Protection (MDEP) is the state agency responsible for managing water resources and issuing Water Quality Certifications (WQC) for licenses that may include compulsory conditions such as minimum and maximum flows, lake level management, habitat restoration, and provisions for the establishment of fish passage facilities, studies, and monitoring.

Traditionally, hydropower regulation has been governed unilaterally by FERC, however, the relicensing process has become increasingly inclusive. This inclusivity, known as collaborative governance, has been attributed to increases in environmental benefits and distribution of decision-making power in the last several decades (Blumm and Lang, 2015). Collaborative governance may broadly be seen as decision-making processes that engage stakeholders across “*the boundaries of public agencies, levels of government, and/or the public, private and civic spheres*” (Emerson et al., 2012). The environmental movement in the United States in the 1970s largely set the stage for this shift. Legislative action during this time established important environmental law including the National Environmental

Policy Act (NEPA; 1970), Clean Water Act (CWA; 1972), Endangered Species Act (ESA; 1973), and Magnuson-Stevens Fishery Conservation and Management Act (MSA; 1976) which empower regulatory and resource agencies in the relicensing process. In effect, FERC makes the final determination on licenses but is obligated to include terms and conditions given by federal and state resource and regulatory agencies based on the statutes above.

The NEPA requires that FERC prepare assessments to evaluate the environmental impacts of proposed projects and assess cumulative impacts. Section 401 of the CWA, administered by MDEP, requires Water Quality Certification for projects to be licensed (33 U.S.C. § 1341(a)(1)). Section 7 of the ESA requires that FERC consult with the federal agency responsible for the management of existent endangered species (either USFWS or NOAA) and obtain that agency's Biological Opinion on measures to avoid jeopardy and "take" of species. The MSA, has increasingly required FERC to consult with NOAA on all actions that may adversely affect essential fish habitat for sea-run fish. Similarly, section 18 of the FPA allows NOAA to make mandatory fish passage prescriptions that must be included in final licenses (16 U. S. C.).

This platform has allowed for more consistent and structured input from various agencies at different points in the policy process (Richardson, 2000; Ulibarri, 2015). The choices made during relicensing are especially important to the long-term survival and persistence of sea-run fish. However, the decision-making process is not always clear. To this end, the objectives of this research are to, 1) identify the primary factors that influence fish passage decision-making including shifts in priority issues and concerns over time, 2) identify agency stakeholders involved in the process and describe patterns in agency engagement, and 3) assess how these factors may hinder or support efforts at integrative, basin-scale hydropower planning. This information may be used to inform future relicensing decisions.

Methods

Document Analysis

One hallmark of the digital age is the increasing rate at which unstructured data is produced in the form text documents, images, presentations, audio files, etc. This is no less true in hydropower management. Given the complexity of the regulatory framework, increasing stakeholder participation, and more stringent record keeping, the FERC hydropower process has generated copious documents related to energy projects. These archived documents contain valuable information but require extensive processing to become useful to decision-makers. Document analysis enables systematic review of documents and interpretation to identify common patterns and emergent themes in the context of agency relicensing decisions (Bowen, 2009; Krippendorff, 2018).

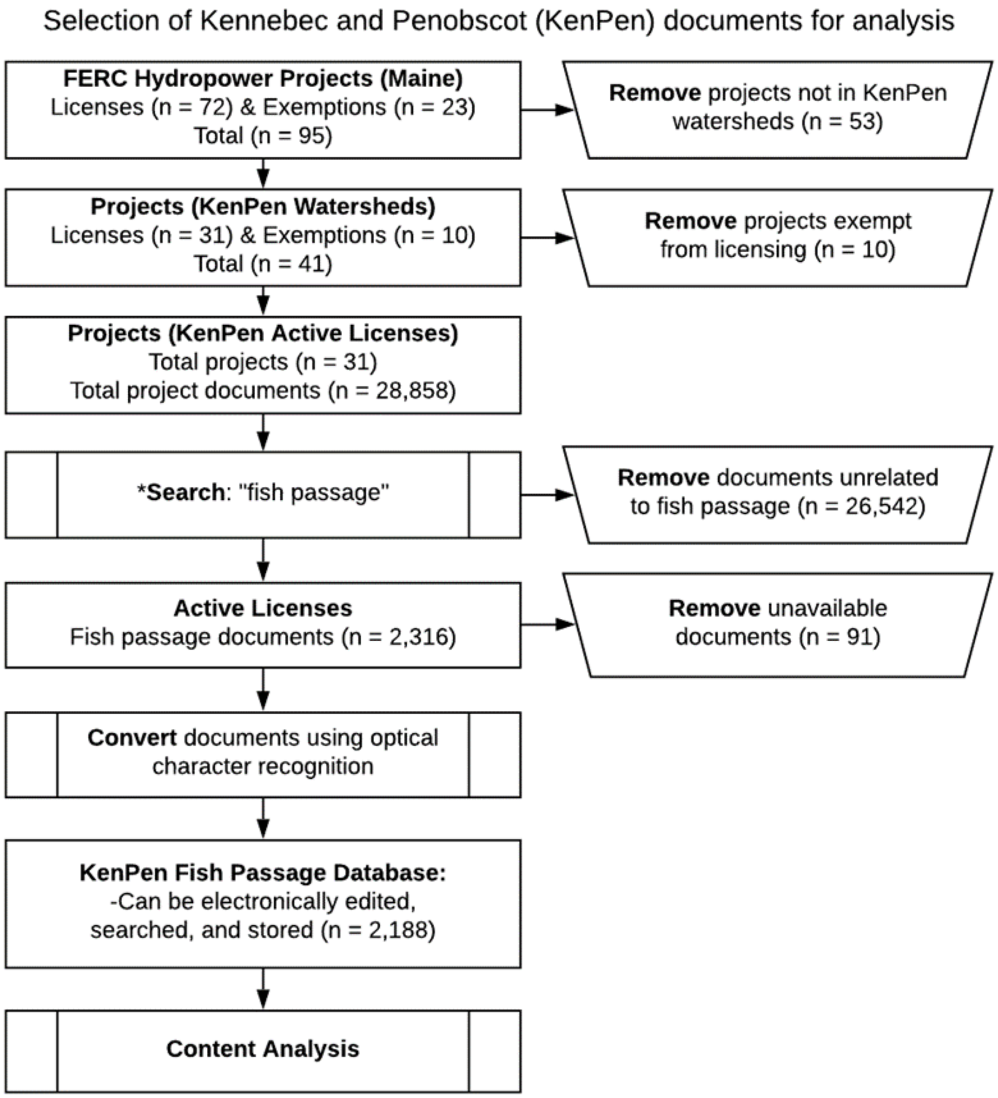
We used qualitative and quantitative document analysis techniques and applied them to FERC-regulated dams on the Kennebec and Penobscot Rivers (Riffe et al., 2014; Table 1.1). This approach allowed us to gain an understanding of fish passage issues specific to the study area while investigating more generalizable themes (Creswell and Plano Clark, 2011). We systematically developed a database of relevant fish passage and hydropower documents and assigned labels ("codes" hereafter) to denote meaningful units of content. We evaluated emerging themes and patterns in the data. We then used text frequencies to measure change in priority issues over time and to identify important process trends. While documents are not necessarily complete records of events that have occurred (Bowen, 2009), they provide unobtrusive and suitable material for systematically assessing the record of fish passage decision-making, investigating stakeholder interactions, and identifying sources of discourse in relicensing (Johnson et al., 2015).

Database Description and Document Discovery

Documents were obtained from the FERC eLibrary (https://ferc.gov/docs-filing/elibrary.asp), a publicly available repository of project specific documents from 1989 to present day (FERC Documents &

Filing, 2011). These include licenses, settlements, safety reports, studies, orders, and all comments and correspondences relating to specific projects. Fully electronic documents are available from 1995-present, with previous years available on microfilm.

To isolate documents related specifically to the Kennebec and Penobscot River watersheds, we performed docket searches that allowed us to access the entire recorded history for each project (“docket” hereafter). We assessed differences in docket size and identified unique challenges and participating stakeholder. As of December 31, 2017, this included 28,858 documents from 31 active hydropower projects and 10 projects exempt from licensing (Figure 1.2) that comprised our initial database. The database was further narrowed to include only documents referencing fish passage. Using built-in search functionality, documents were identified and downloaded using *“fish passage”* as an exact phrase search parameter. “Fish passage” is a term that In addition to *“fish passage,”* we explored other terms (e.g., “*fish”*, “*migration”*, “*fishway-“*, “*eelway-“*, and “*passage”).* We found that “*fish”* and “*migration”* led to results that were much broader than warranted (e.g., returned entries for all fish, including those with no passage concerns), while “*fishway-“* and “*eelway-“* led to excessively narrow results due to the specificity of the terms and were redundantly captured in the “fish passage” search. “P*assage”* returned substantial results but included references to all types of passage (e.g., boat passage). From this exercise, the parameter, *“fish passage,”* was deemed the most appropriate for our needs and reduced the number of documents available for content analysis to 2,316 (Figure 1.2).



*Performance relies on search terms being identifiable within the body of text documents and FERC eLibrary descriptions and may not account for scanned images, non-OCR, and other types of non-searchable documents.

Figure 1.2. Fish passage document database. Selection process for compiling a fish passage database related to active hydropower projects in the Kennebec and Penobscot River watersheds in Maine. Documents were subsequently imported into NVivo software (QSR International Pty Ltd. Version 11 Plus, 2015) for further storage and content analysis.

Given the presence of the term *"fish passage"* in older documents, we assumed that the term effectively captured most documents relating to the passage of fish through, past, or around hydropower projects. We do acknowledge that this sample is not a complete record of all fish passage documentation in our study area. Several limitations exist relating to restrictions in *i*) search capabilities, *ii*) document quality, *ii*) document availability, *iv*) timing, and *v*) regulation changes. For example, the search function relies on content being recognized as text. Most modern text files (e.g., .pdf, .txt, .doc, etc.) were fully searchable while scanned image files (e.g., .jpg, .png, etc.) were not. Where possible, image files were transformed into searchable documents using Optical Character Recognition software (ABBYY FineReader 14, ABBYY North America, Milpitas, CA). Older documents of poor digital quality were not recognized through text searches and some documents dated prior to the 1980s were not available. Likewise, Critical Energy Infrastructure Information (CEII) could not be accessed without special clearance through the Freedom of Information Act. Finally, record keeping requirements have developed to be more extensive over time, leading to a prevalence of newer documents in proportion to older documents. Regardless of these limitations, it was ultimately concluded (in consultation with a representative from FERC) that most pertinent documents would be found using our search method. In this manner, a final fish passage archive was created, consisting of text-searchable documents (*n* = 2,188; Figure 1.2).

General themes for individual projects were initially generated from the database using the auto coding feature in the computer assisted qualitative data analysis software, NVivo (QSR International Pty Ltd. Version 11 Plus, 2015). This gave us a preliminary view of broad subject matter based on word frequencies and allowed us to make general comparisons among projects. In addition to the fish passage database, separate searches were performed for each project to isolate process-specific documents that were mandatory and/or highly common in relicensing irrespective of whether they addressed fish passage (e.g., pre-application documents, study plans and reports, Biological Opinions, mandatory condition license prescriptions, Environmental Assessments, Scoping Documents, and final licenses (LIC)). These documents were identified from the Federal Power Act (16 U.S.C. § 791) and the FERC Hydropower Primer (FERC, 2017) and represent the minimum document requirements for decision-making in the relicensing process.

Summarizing Characteristics of Hydropower Projects

In order to examine possible factors relevant to fish passage decision-making, variables were extracted from the fish passage database representing social and procedural, physical, and biological features of hydropower projects (Tables 1.2-1.4). Factors were chosen based on their possible influence on the decision process based on document review, informal conversations with relicensing participants, professional presentations, and literature reviews. Factors were reduced to 13 social and procedural, 11 physical, and 9 biological variables for analysis (Tables 1.2-1.4).

The social and procedural features (Table 1.2) represent important facets of the human interactions in relicensing. For instance, the total number of documents attributed to projects (DOCS), the proportion of documents relating to fish passage (FPDOCS), and the number of intervention requests and comments (INTERV; CMNT) generally denote stakeholder interest and involvement in particular projects. The project owner (OWNR), owner type (OWNRCAT), population density (POP), and potential hazard to the downstream areas (HAZD) may affect this involvement. Procedural features such as the year the most recent license was issued (YR), term length for the current license (TERM), relicensing process used (PROCESS), and the inclusion of low impact hydropower certification (LIH), attempt to situate the projects in regulatory space and time.

The physical variables (Table 1.3) attempt to situate projects in geographic space and are descriptive of project facilities. River designation (HUC8), river size (RIVSIZE), nearness to the mouth of the network in river kilometers (RKM), the presence of a head pond (POND), storage capacity (STG), and drainage area (DRAIN) generally describe the river system and watershed. Project facilities are described by the number of dams associated with each project (DAMCT), their authorized hydropower capacity (AUTH), dam height (HT), flow regime (FLOW; run-of-river, storage, combination), and primary function (PURPOSE; hydropower, flood control, water supply, other). Unless otherwise noted, metrics for multi-dam projects were averaged, representing the average condition for the entire dam complex.

Biological variables (Table 1.4) generally relate to the presence of migratory fish (MIGFISH) and federally endangered species (ENDSP). Specifically, they assess whether projects occupy one of three Salmon Habitat Recover Units (SHRU; Penobscot, Merrymeeting, and Downeast) and salmon critical habitat (CRITHAB). They also include the number of hydropower and impassable barriers downstream (HYDRO; IMPASS), the total number of barriers upstream (BARUP), and the amount of blocked upstream salmon and alewife habitat (SALHAB; ALWHAB). These features are important considerations for management concerns and stakeholder involvement.

Table 1.2. Social and procedural variables investigated at hydropower dams in the Kennebec and Penobscot Rivers. Reported are the variable code, description, and relevance to research into fish passage decision-making during hydropower relicensing. All variables were used for non-metric multi-dimensional scaling analysis (Figures 1.3 & 1.4). Random forest model (Figure 1.6) variables selected for explaining variation in agency involvement among FERC-regulated hydropower projects are marked with an asterisk.

Variable	Description	Relevance
SOCIAL AND PROCEDURAL ATTRIBUTES		
OWNR	Parent company of licensee (wholly owned subsidiaries are assumed to be under the direct control of the parent company)	Represents the highest functional level of ownership at which decisions get made
OWNRCAT*	Ownership category of the parent company, representing government, municipal, private, NGO, and individuals	Different types of owners may exhibit different management styles, problem solving, resource allocation, etc.
INTERV	Number of intervention requests by in project docket	Intervenors may influence decision-making
CMNT	Number of comments in project docket	Comments may influence relicensing and indicate desirable of outcomes
STKPART	Summation of comments and intervention requests in project docket	Measure of stakeholder participation that may indicate active involvement in relicensing and shed light on objectives and concerns
POP	Population in 10km radius around dam as given by FreeMapTools.com which uses 2010 Census Data and crosschecked with Circular Area Profile (average taken for multi-project dams)	May impact community and agency involvement, resources availability, and concern for relicensing proceedings
DOCKET	Number of documents included in project docket as of 12/31/2017	May indicate which projects receive the most stakeholder attention, controversy, impact, etc.
FPDOCS	Proportion of documents relating specifically to fish passage as of 12/31/2017 through a general search of "fish passage" in the FERC eLibrary	May indicate which projects observe more challenges relating to, and concern for, fish passage
HAZD*	Potential hazard to the downstream area resulting from failure or mis-operation of the dam (low, significant, and high; highest hazard potential listed for multi-dam projects)	Potential hazard may influence emergency action plans and prioritize safety in relicensing
YR*	Year of the most recent license was issued	Contributes to timeline and situates projects in regulatory space
TERM*	License term given in most recent license (generally 30, 40, or 50 years, but may be adjusted for basin management)	Meant to offset uncertainty and investment expected from licensee as part of the licensing process (default: 40 years as of 2018)
PROCESS*	Process used in most recent relicensing effort (TLP, ALP, or ILP)	The licensing process can indicate the level of coordination and engagement expected of stakeholders.
LIH*	Low impact hydro certification as determined by the Low Impact Hydro Institute	Certification may correlate with environmental measures and stakeholder involvement

Table 1.3. Physical variables investigated at hydropower dams in the Kennebec and Penobscot Rivers. Reported are the variable code, description, and relevance to research into fish passage decision-making during hydropower relicensing. All variables were used for non-metric multi-dimensional scaling analysis (Figures 1.3 & 1.4). Random forest model (Figure 1.6) variables selected for explaining variation in agency involvement among FERC-regulated hydropower projects are marked with an asterisk.

Variable	Description	Relevance
PHYSICAL ATTRIBUTES		
HUC8*	River designation based on Hydrologic Unit Code from the USGS, includes the LowerKen, Piscataquis, Dead, LowerPen, WestBranchPen, and Sebec Rivers	River designation factors into regional participation and basin management
RIVSIZE*	River size class based on NE Aquatic Habitat Classification, including small rivers, medium tributary rivers, medium mainstem rivers, and large rivers	River size may factor into regional participation, basin management, and environmental concerns
POND*	Presense/absence of pond within 30 m of the dam. Projects with more than one dam were given the designation of "present" if at least one dam had an associated pond.	Presence of impoundment important to
RKM*	Distance from dam to the network mouth in kilometers. For multi-dam projects, the lowest number was recorded to represent the most seaward dam in the complex.	The distinction of where a project is located can impact management, what types of fish occupy project waters, stakeholder engagement, and recreational use
DAMCT*	Number of dams associated with each project, ranging from 1-9	May have implications for the coordination of mngt among dams, regions, waterbodies, and stakeholders
AUTH*	Authorized hydropower capacity in gigawatts under current license (not a measure of "actual" generation)	Generation capacity may relate to the size and impact of a project and may determine stakeholder engagement and conservation efforts
PURPOSE*	Primary purpose of project given by the USACE National Inventory of Dams database, including hydropower, water supply, flood control, and fish/wildlife	Poses different challenges relating to water use, inundation, habitat, recreation, priority of resources, and relicensing objectives
FLOW*	Mode-of-operation (run of river, storage, or combination)	Flow regimes may relate to specific impacts to fish and wildlife habitat above and below the project
HT*	Height of the dam, defined as the vertical distance between the streambed and crest of the dam (average taken for multi-dam projects)	Height corresponds to dam size and may influence regulatory concern, project impacts, recreation, and stakeholder input
STG*	Normal storage, defined as the total storage space in a reservoir below the normal retention level (average taken for multi-dam projects)	Impoundment size may relate to project impacts, recreation, and licensing objectives
DRAIN*	Drainage area above a project (average taken for multi-dam projects)	Area above projects may relate available wildlife habitat, recreation, passage concerns, and stakeholder input

Table 1.4. Biological variables investigated at hydropower dams in the Kennebec and Penobscot Rivers. Reported are the variable code, description, and relevance to research into fish passage decision-making during hydropower relicensing. All variables were used for non-metric multi-dimensional scaling analysis (Figures 1.3 & 1.4). Random forest model (Figure 1.6) variables selected for explaining variation in agency involvement among FERC-regulated hydropower projects are marked with an asterisk.

Variable	Description	Relevance
BIOLOGICAL ATTRIBUTES		
MIGFISH*	Number of anadromous species with documented habitat directly downstream of project based on current habitat conditions (includes alewife, blueback herring, American shad, striped bass, Atlantic salmon, and Atlantic sturgeon; highest value assigned for multi-dam projects)	Species present at projects can affect license terms and conditions, fish passage, environmental measures, and stakeholder involvement
SHRU*	Salmon Habitat Recovery Units for the Gulf of Maine Atlantic salmon Distinct Population Segment (Penobscot, Merrymeeting, and Downeast)	Much of Atlantic salmon conservation is based on defined Habitat Recovery Units
CRITHAB*	HUC 10 watersheds that have been classified as Critical Habitat under the Endangered Species for Atlantic salmon (Kennebec at Waterville, Penobscot at Veazie, Penobscot at West Enfield, and Penobscot at Mattawamkeag)	Much of Atlantic salmon conservation is based on defined Critical Habitat
ENDSP*	Presence/absence of federally endangered species with habitat directly downstream of project (Atlantic salmon, Atlantic sturgeon, and shortnose sturgeon.)	Presence of endangered species influences stakeholder participation and engenders protections not given to all species
IMPASS*	Number of “impassable” barriers downstream of a project (highest number recorded for multi-dam projects)	Number of barriers downstream may influence basin-wide planning and scheduling for fish passage
HYDRO*	The number of hydropower dams downstream of a given barrier. For projects with more than one dam, the highest number was recorded to represent the maximum obstacle for fish passage, except in the case of Milford dam which does not account for the non-generating Gillman Falls. SOURCE: NCAT	The number of barriers downstream may influence basin-wide planning and scheduling for fish passage. Hydropower dams especially are encouraged to manage planning on a basin-wide scale.
BARUP*	The total number of barriers (regardless of impassability or hydropower designation) upstream of a given barrier. For projects with more than one dam, the average number of barriers was recorded to represent the average fish passage obstacles for each respective hydropower complex. For removed projects, the number of upstream barriers were duplicated from the closest upstream project. SOURCE: MDMR's Stream Habitat Viewer	The number of barriers upstream and available habitat may influence basin-wide planning and scheduling for fish passage
SALHAB*	The number of Atlantic Salmon modeled habitat units (100 sq m) that are blocked by the given barrier. For projects with more than one dam, the average salmon habitat was calculated to represent the average habitat available within each respective hydropower complex. SOURCE: MDMR'S Maine Stream Viewer	The amount of available habitat upstream may influence conservation decisions for certain species
ALWHAB*	The number of Alewife pond acres that are blocked by the given barrier. For projects with more than one dam, the average alewife pond habitat was calculated to represent the average habitat available within each respective hydropower complex. SOURCE: MDMR'S Maine Stream Viewer	The amount of available habitat upstream may influence conservation decisions for certain species

Summarizing Project Outcomes

Because final licenses ultimately represent the culmination of each relicensing process, we focused on characteristics that could be mined directly from the text of each license. Licenses represent a direct response to prior decision-making in the system. For this reason, we did not consider amendments made after licensing, additional arbitration, or the subsequent evaluation of licensing compliance. This allowed us to investigate concepts related to fish passage decisions such as *i*) fish management, *ii*) stakeholder engagement, and *iii*) basin-scale planning. Term frequency searches were performed using NVivo software (QSR International Pty Ltd. Version 11 Plus, 2015). Unless indicated by closed quotation marks, all searches were inclusive of stemmed words and used Boolean functions to add search parameters. The license for the Great Works project was not available and therefore was not included in the analysis. The search parameter (SP) for a term, number of licenses containing the term, average term frequency, SD, and maximum term frequency are reported (Table 1.5).

Table 1.5. License term frequency. Text searches of hydropower licenses examining species of concern, fish passage including mitigative measures, basin management, and stakeholder participation including the invocation of licensing authorities. Searches were performed using NVivo software (QSR International Pty Ltd. Version 11 Plus, 2015). Unless indicated by closed quotation marks, all searches were inclusive of stemmed words and used Boolean functions to add search parameters. Average term frequency, SD, number of licenses containing the term, and maximum term freqrequency are reported.

Category	Code	Variable description and search parameter (SP)	Average term frequency
Species of concern	EEL	American eel (SP: eel)	16.8 ± 33.5 (11 projects; max 140)
	SHAD	American shad (SP: shad)	3.4 ± 7.0 (10 projects; max 31)
	ALW	River herring (SP: alewife)	1.7 ± 3.5 (7 project; max 16)
	SALM	Atlantic salmon (SP: salmon)	16.8 ± 24.5 (24 project; max 98)
Mitigation	FPUP	Upstream fish passage (SP: “upstream fish” OR “upstream passage”)	5.6 ± 11.1 (17 project; max 47)
	FPDN	Downstream fish passage (SP: “downstream fish” OR “downstream passage”)	10.3 ± 19.3 (17 project; max 95)
	FPALL	Total fish passage calculated as a sum of up and downstream passage	15.9 ± 29.8 (17 project; max 142)
	STOCK	Stocking effort (SP: stock)	3.2 ± 4.3 (15 project; max 15)
	FUND	Mitigation funding (SP: fund)	5.6 ± 8.3 (18 project; max 31)
	SETTLE	Settlement agreement (SP: settlement OR agreement)	11.7 ± 25.6 (9 project; max 95)
Entities	USFWS	U.S. Fish and Wildlife Service (SP: “fish and wildlife service” OR USFWS OR FWS)	14.8 ± 11.6 (26 project; max 37)
	NOAA	NOAA Fisheries (SP: “oceanic and atmospheric” OR NOAA OR “marine fisheries service” OR NMFS)	5.4 ± 11.1 (19 project; max 59)
	MDEP	Maine Dept. of Environmental Protection (SP: “department of environmental protection” OR MDEP OR DEP)	8.2 ± 5.3 (29 project; max 20)
	MDIFW	Maine Dept. of Inland Fisheries and Wildlife (SP: "inland fisheries and wildlife" OR MDIFW OR MIFW OR IFW)	9.8 ± 7.5 (27 project; max 33)
	MDMR	Maine Dept. of Marine Resources (SP: "department of marine resources" OR MDMR OR DMR)	7.4 ± 13.0 (15 project; max 62)
	PIN	Penobscot Indian Nation (SP: "Penobscot Indian Nation" OR "the Nation" OR PIN)	13.1 ± 30.0 (17 project; max 115)
Regulatory statutes	WQC	Under CWA section 401, states must certify that the project will comply with applicable water quality standards (SP: “water quality certification”)	8.7 ± 5.7 (24 project; max 20)
	SEC18	Under FPA section 18, fishway prescriptions can be administered by USFWS and NOAA Fisheries (SP: “fishway prescription” OR “section 18” OR “sec 18”)	4.1 ± 6.0 (23 project; max 34)
	10J	Under FPA section 10(j), licenses are required to “adequately and equitably protect, mitigate damages to, and enhance fish and wildlife...” (SP: “10(j)”)	5.8 ± 5.7 (21 project; max 28)
	10A	Under FPA section 10(a)(1-2), projects must serve the public interest in the river basin and consider recognized comprehensive plans (SP: “10(a)”)	2.3 ± 1.8 (18 project; max 5)
	ESA	Under ESA section 7(a)(1), FERC must protect and contribute to the recovery of all threatened and federally endangered species affected by projects (SP: “endangered species”)	2.2 ± 2.0 (18 project; max 9)
	CZM	Under Coastal Zone Management Act section 307, projects must be consistent with coastal zone management programs (SD: “coastal zone”)	0.7 ± 1.9 (5 project; max 9)
Complexity	BASIN	Management complexity index calculated from references to other projects within each license	0.43 ± 0.39 (range 0-1.6)

First, we investigated fish management by searching for specific terms in final licenses related to fish species and mitigation measures. We explored searches for any species that might have occupied project waters. Species of concern were identified as those mentioned more than once, and in more than one license. Species of concern included American eel, Atlantic salmon, American shad, and river herring (Table 1.5). Mitigation measures that were investigated included upstream and downstream fish passage, conservation funding, fish stocking, and settlements (Table 1.5). We did not include searches for specific types of fish passage as they are not consistently referenced in final project licenses.

Stakeholder engagement was assessed by searching license text for references to known process participants and their mandated authorities. We assumed that active stakeholders would be mentioned in the license text more often than inactive stakeholders, due to mandatory and traditional standards for reporting intervenors, commenters, and negotiation participants Identified stakeholders included federal resource agencies (NOAA and USFWS) and state resource agencies (MDEP, MDIFW, and MDMR) (Table 1.5). Licensing authorities included WQC (administered by MDEP; CWA, section 401), fish passage prescriptions (NOAA and USFWS; FPA, section 18), and Endangered Species Act consultation (NOAA and USFWS). Statutes requiring interagency collaboration and shared administration included comprehensive planning considerations (FPA, section 10(a)), the *Protection of Fish and Wildlife* (FPA, section 10(j)), and *Coastal Zone Management* (CZMA, section 307).

Finally, management complexity was assessed by searching individual licenses for references to projects besides their own. The assumption was made that projects that were co-managed would reference each other frequently. A management complexity index was calculated for each project based on the number of times co-managed projects were referenced in the project license (Table 1.5). This was done by calculating the ratio of co-managed references in relation to the number of self-references in each license where *i* is the first dam interaction and *n* is the total number of dam interactions.

$$management\ complexity\ = \sum_{i=1}^{n} \frac{co\ managed}{self\ reference}$$

For example, a project that referenced itself 10 times and referenced another project 5-times would have a ratio of 5/10, or 0.5 for that interaction. This allowed us to normalize values among projects that were naturally text light or heavy, and those that did not frequently reference any projects, including their own. These values were then summed to create the index. Higher scores represent higher levels of basin-scale planning.

Assessing Project Variation and Predictive Factors

In order to infer relationship patterns among projects we used a combination of non-metric multidimensional scaling (NMDS) and random forest modeling. NMDS was used to graphically represent similarities among projects in two-dimensional space (McCune et al., 2002). NMDS is an ordination technique that assesses pairwise distance information between variables based on a rank order of (dis)similarities (Borg and Groenen, 1997). Distances are plotted into two-dimensional space using principal component analysis rotation so that the x-axis (NMDS 1) reflects the primary sources of variation in the data, followed by the y-axis (NMDS 2; Oksanen et al., 2019). We used the *metaMDS* routine in package *vegan* (Oksanen et al., 2019) in program R 3.6.1 (R Core Team, 2019). Ordinations were based on Euclidean distance and the maximum number of random starts in the search for a stable solution was increased from 20 (default) to 500. Three projects were excluded from analysis due to incomplete data for all variables. These were Great Works and Veazie which were removed in 2012 and 2013 and Howland which was decommissioned.

NMDS was used to visualize the level of similarity among projects given their social (n = 13), physical (n = 11), and biological (n = 9) characteristics (Tables 1.2-1.4, respectively). Polygons were used to visualize groupings of projects by their location on the river in kilometers (RKM). This was categorized based on histogram groupings with three bins: *i*) coastal projects (n = 46.24 – 131.97 RKM), *ii*) midway projects (n = 131.97 – 217.7 RKM), and *iii*) inland projects (217.7 – 303.43 RKM). This was followed by a second NMDS to assess relationship patterns based on final project outcomes (i.e., official licenses). Specifically, license term frequencies (n = 23; Table 1.5) were used to characterize similarities among projects. Polygons were used to visualize groupings of projects by the year licenses were issued.

Finally, a random forest model was used to describe the relative importance of a subset of the social, biological, and physical factors (Tables 1.2-1.4, respectively) on fish passage concern. A reduced number of project characteristics were used in order to comply with the model conventions (i.e., the number of variables could not exceed the number of projects). Variables that were removed showed low diagnostic power in relation to the first NMDS. We conceptualized our response variable (fish passage concern) as the ratio of fish passage related documents to the total number of documents for a project. We assumed that projects with a relatively high proportion of fish passage related documents would equate to relatively high concern for fish passage.

Random forest is a type decision tree classification algorithm that splits data based on variable characteristics. It computes many decision trees and outputs the mean prediction of the combined trees. It can accommodate different types of data without rescaling (e.g., binary, categorical, numeric, etc.), handles unbalanced data well, and exhibits low bias while estimating variable importance (Breiman, 2001). We used package *randomForest* (Liaw and Wiener, 2002) in program R version 3.6.1 (R Core Team, 2019). We used default parameters for the model but increased the number of decision trees from 500 to 4000 and reduced the number of randomly sampled variables for candidates at each split from 6 to 4. Variable importance was assessed using the *importance* function in *randomForest.* This function assumes that variables attributed to relatively high increases in node purity, equate to relatively high importance in predicting fish passage concern. We note that “importance” is not statistically equivalent to mean effect size. For this reason, variables could have a larger impact on fish passage concern despite low relative importance, and vice versa (Honsey et al., 2018). Great Works, Veazie, and Howland were excluded from this analysis.

Results

Project Characteristics and Outcomes

The overall number of documents in each project docket ranged from 174 - 2355 (mean 915.1 ± 428.5; Table 1.1). In general, older licenses were shorter in length and less comprehensive than newer licenses. For example, the Brassau license (1977) consisted of 19 pages of text and 9,050 words while the American Tissue license (2019) consisted of 114 pages and 30,800 words, representing a 340% difference in word count. Licenses from the 1970-80s primarily addressed the need for power, economic feasibility, and human benefits. Documents referencing fish passage accounted for 9.3% of each project's docket, however, these ranged greatly from 0.5 to 25.2% (Table 1.1).

Fish Management

Among the species of concern identified in project licenses, American eel was the most frequently mentioned species occurring in 11 licenses a maximum number of 140 times in a single license (16.8 ± 34.2; Table 1.5). Atlantic salmon were the second most frequently mentioned fish species occurring in 24 licenses (16.8 ± 25.0; max 98). Both Atlantic salmon and American eel exhibited an increase in priority over time, as measured by text frequency, with American eel exhibiting a sharp increase after the 1990s (Figure 1.3A). River herring and American shad did not experience a similar trend and term frequency remained low. American shad were mentioned in 10 licenses (3.4 ± 7.1; max 31) and river herring in 7 licenses (1.7 ± 3.5; max 16; Table 1.5).

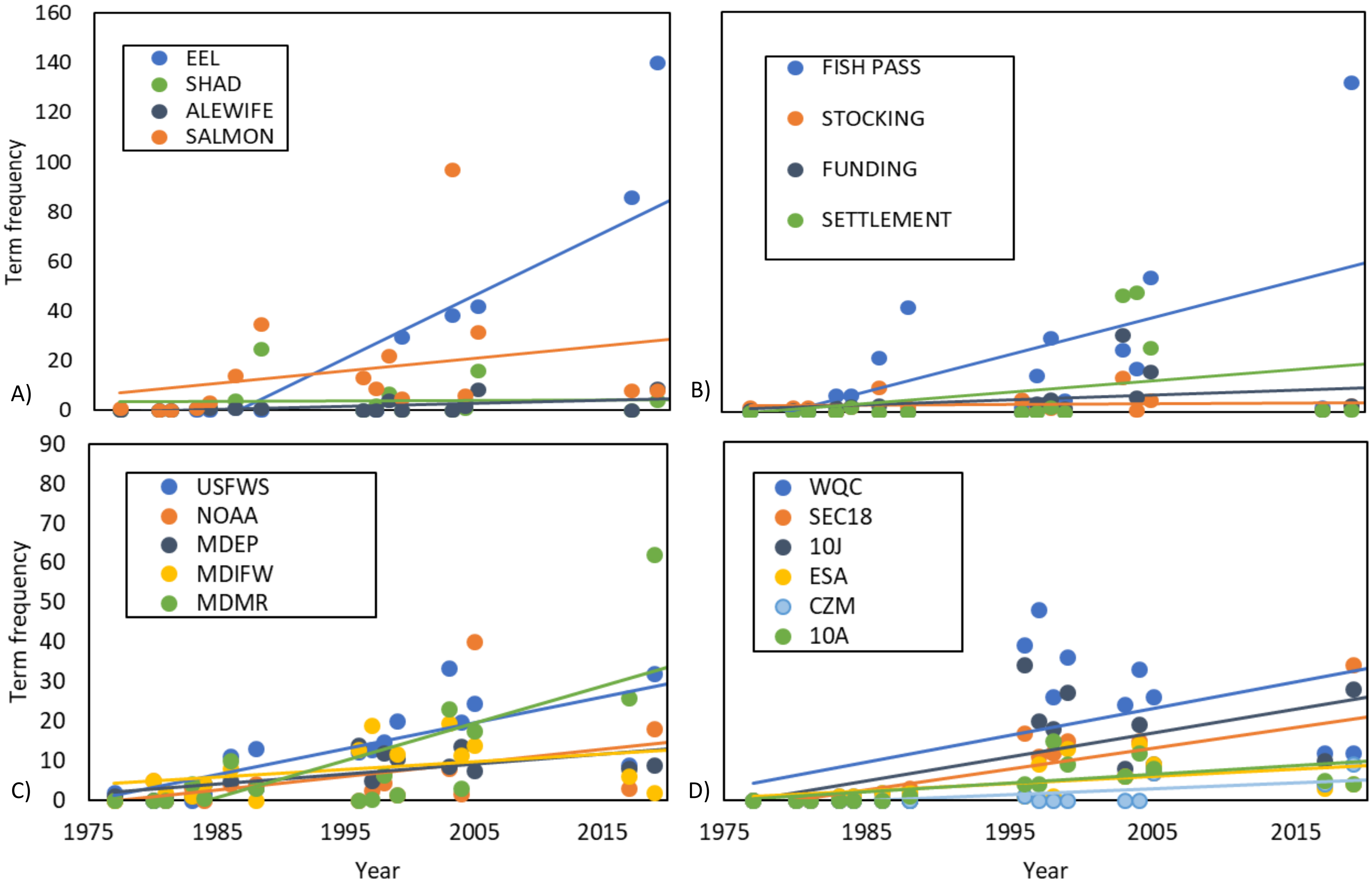


Figure 1.3. Term frequency values by year. A) Fish species, B) fish passage mitigation, C) resource and regulatory agencies, and D) statutes mentioned in project licenses as reported by term frequency searches (Table 1.5) and arranged by the year of license issuance.

We found an increase in fish passage language within project licenses over time (Figure 1.3B). The term *“fish passage”* was referenced in 17 licenses with downstream passage being mentioned more frequently than upstream passage (5.6 ± 11.1; max 47 vs. 10.3 ± 19.3; max 95; Table 1.5). In general, projects closer to the mouth of the watershed (coastal projects) tended to reference fish passage more often than those further inland (inland projects; Figure 1.5). Several inland projects made no mention of passage beyond legal language reserving the right of NOAA and USFWS to prescribe fish passage in the future under section 18 of the FPA. It may be noted that this is common language, often referred to as “boilerplate” in contract law, describing contract parts that are considered standard.

In addition to fish passage, conservation funding was referenced in 18 licenses, a maximum of 31 times in a single license (5.6 ± 8.3). Fish stocking was mentioned in 15 licenses (3.2 ± 4.3; max 15). Conservation funding and fish stocking did not increase with time and were prominent features of older licenses (Figure 1.3B). Settlement agreements were mentioned in 9 licenses (11.7 ± 25.6; max 95; Table 1.5) and were largely absent from project licenses prior to 2005.

Stakeholder Engagement

USFWS was the most frequently and consistently referenced resource agency in project licenses. They were mentioned in 26 licenses, a maximum of 37 times in a single license (14.8 ± 11.6; Figure 1.3c). MDIFW and MDEP were also referenced relatively frequently, in 27 (9.8 ± 7.5; max 33) and 29 licenses (8.2 ± 5.3; max 20), respectively (Table 1.5). MDMR was mentioned in 15 licenses (7.4 ± 13.0; max 62) followed by NOAA in 19 licenses (5.4 ± 11.1; max 59). Overall, there was a slight increase in agency references over time.

Licenses issued after the 1990s saw an increase in term frequency of regulatory statutes (Figure 1.3D). WQC, administered by MDEP under the CWA was referenced most frequently and occurred in 24 licenses (8.7 ± 5.7; max 20; Table 1.5). Fish passage prescriptions under section 18 of the FPA were referenced in 23 licenses (4.1 ± 6.0; max 34), followed by section 10(j) of the FPA in 21 licenses (5.8 ±

5.7; max 28; Table 1.5). Section 10(a) of the FPA, while referenced in 18 licenses, was only referenced a maximum of 5 times in a single license (2.3 ± 1.8). Similarly, while the term “endangered species” was mentioned in 18 licenses, it appeared with relatively low frequency (2.2 ± 2.0; max 9). Coastal Zone Management was the most infrequently referenced regulatory statute in only four licenses (0.7 ± 1.9; max 9; Table 1.5).

Basin-Scale Hydropower Planning

The number and magnitude of projects referenced within a single license, led to the calculation of a management complexity index. Values ranged from 0 (no basin-scale coordination) to 1.6, (indicating relatively high coordination among projects). Overall, projects did not display a high degree of basin-scale coordination (median = 0.28; Table 1.5). Several projects did not reference any projects besides their own. These included Howland (1980), Shawmut (1981), Lowell Tannery (1983), Benton Falls (1984), and American Tissue (2019); Figure 1.1). Several projects were clearly co-managed in pairs (e.g., Abenaki and Anson (2003); Automatic and Messalonskee (1999); and Penobscot Mills and Ripogenus (1996)) which frequently referenced each other (management complexity index range = 0.2 - 1.2). Over half of the projects (58%) referenced fewer than three others.

Variation and Predictive Factors

We obtained stable, 2-dimensional NMDS ordinations (Figure 1.4) for the 33 social, physical, and biological factors (final stress = 0.10) indicating that the data were adequately described by the chosen number of axes (Clarke, 1993). Arrows were applied to indicate diagnostic power with longer arrows being associated with variables that hold relatively high influence. The x-axis ordinated along a coastal to inland gradient (Figure 1.4). Negative values along the axis were more closely associated with large areas of blocked alewife habitat (ALWHAB), a higher number of sea-run fish (MIGFISH), the presence of federally endangered species (ENDSP), more densely populated areas (POP), and Low Impact Hydropower Certification (LIH; Figure 1.4). Positive values were more closely associated with higher storage capacity (STG), a large number of impassable downstream barriers (IMPASS), and the presence of an impoundment pond or lake (POND). These characteristics were diagnostic of how hydropower projects oriented in this space. Projects closer to the coast grouped together towards the left while inland storage projects grouped closely with one another towards the right (Figure 1.4).

License term frequencies also produced stable, 2-dimensional NMDS ordinations (final stress = 0.10; Figure 1.5). The y-axis ordinated along a temporal gradient. Positive values along the axis were more closely associated with downstream fish passage (FPDN) and fish stocking (STOCK; Figure 1.5). Conversely, many term frequencies ordinated negatively, including all regulatory statutes (e.g., CZM, ESA, WQC, 10J, 10A, and SEC18). When compared to project ordinations in this space, a temporal division was observed. Projects licensed prior to 1900 grouped together (n = 7) towards the top of the graph, while projects licensed after 1995 grouped together (n = 21) towards the bottom (Figure 1.5B).

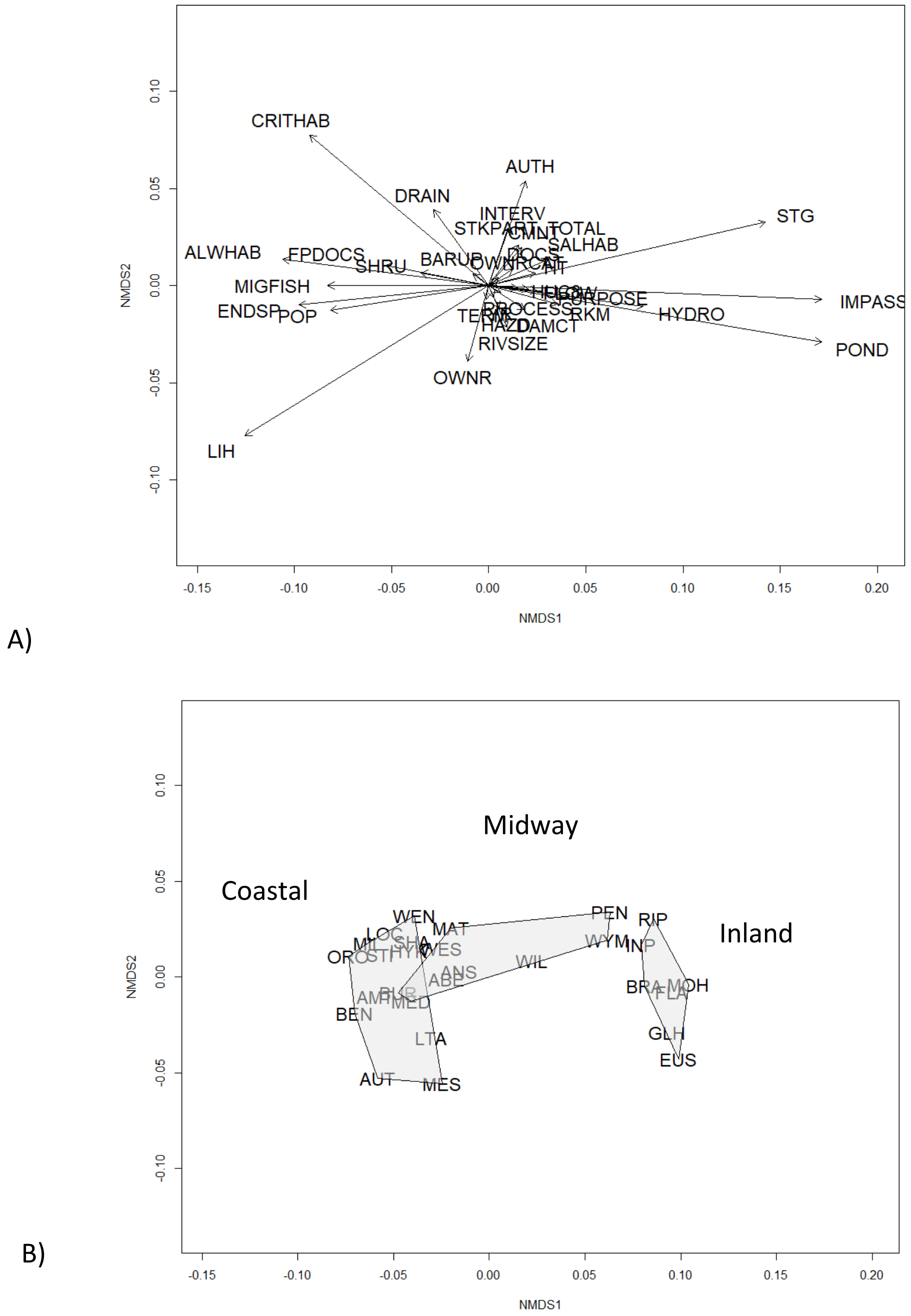


Figure 1.4. NMDS of hydropower project characteristics. A) Ordinations of 33 social, physical, and biological project characteristics of hydropower dams (Tables 1.2-1.4, respectively). Arrows represents variable loadings and longer arrows are associated with relatively strong diagnostic variables. B) Hydropower projects. Polygons are based on project locations in river kilometers: (from left to right) coastal projects (46.24 – 131.97 RKM), midway projects (131.97 – 217.7 RKM), and inland projects (217.7 – 303.43 RKM). Closeness between projects indicate similar project characteristics.

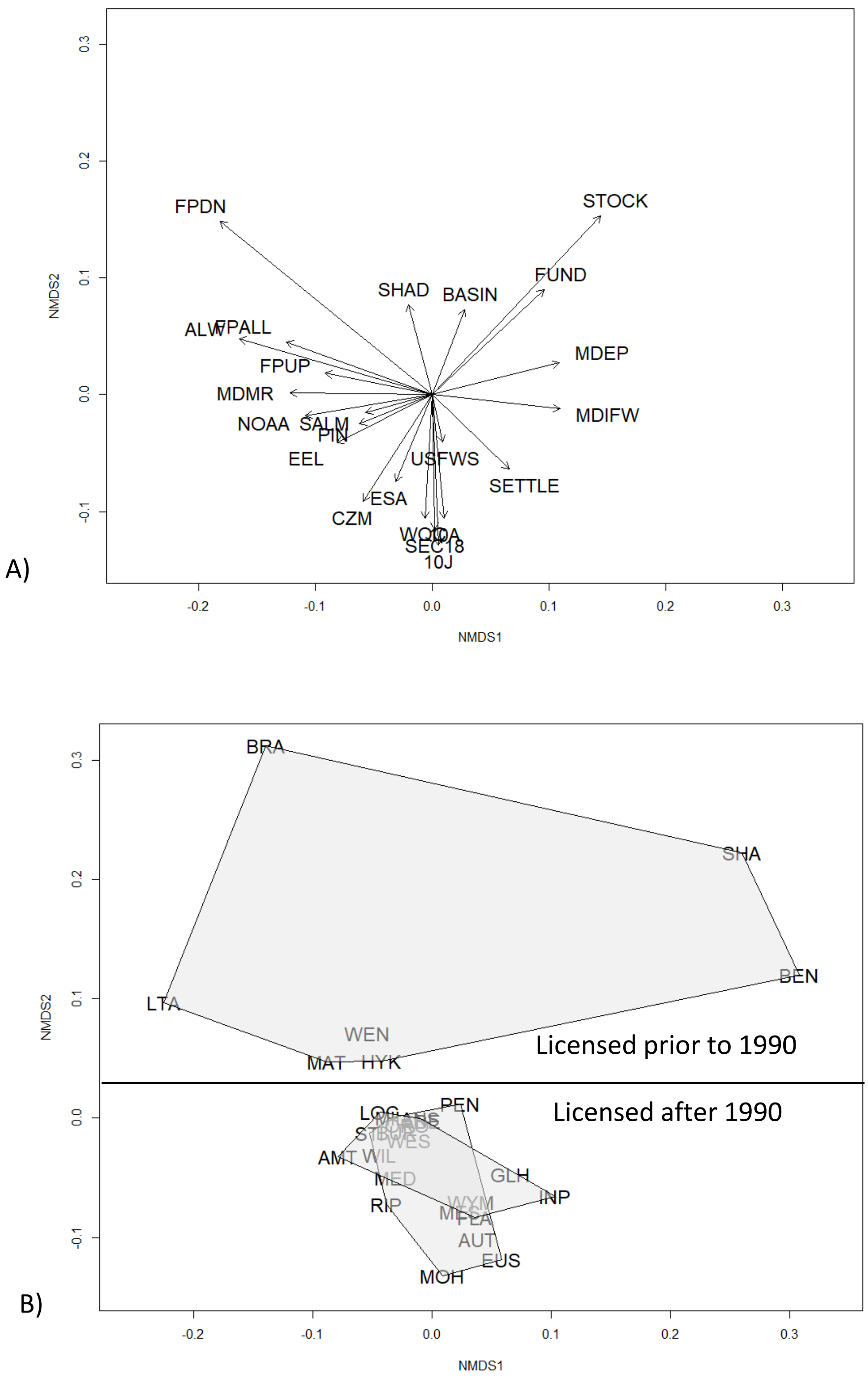


Figure 1.5. NMDS of license term frequencies. A) Ordinations of term frequencies in hydropower licenses (Tables 1.5). Arrows represents variable loadings and longer arrows are associated with relatively strong diagnostic variables. B) Hydropower projects. Polygons are based on the year of license issuance. Closeness between projects indicate similar project characteristics.

Random forest modeling was used to describe the relative importance of project characteristics (Tables 1.2-1.4) for explaining variation in fish passage concern, represented by the proportion of fish passage related documents for each project. Our model explained 51% of the variation in fish passage documents. Node purity (measured by the residual sum of squares) from splitting on a given variable was averaged over all decision trees. Variables that were attributed to a relatively high increase in node purity overall, were ranked relatively important in predicting fish passage concern (Figure 1.6). Variables of high importance were the number of hydropower projects downstream (HYDRO), a large amount of blocked alewife habitat (ALWHAB), the presence of a large impoundment (POND), and the number of sea-run fish in the project area (MIGFISH; Figure 1.6). Variables of moderate importance were placement on the river (RKM), the size of the river drainage above a project (DRAIN), population density (POP), and the storage capacity of the project (STG; Figure 1.6). The remaining factors had relatively low predicted impacts on fish passage concern.

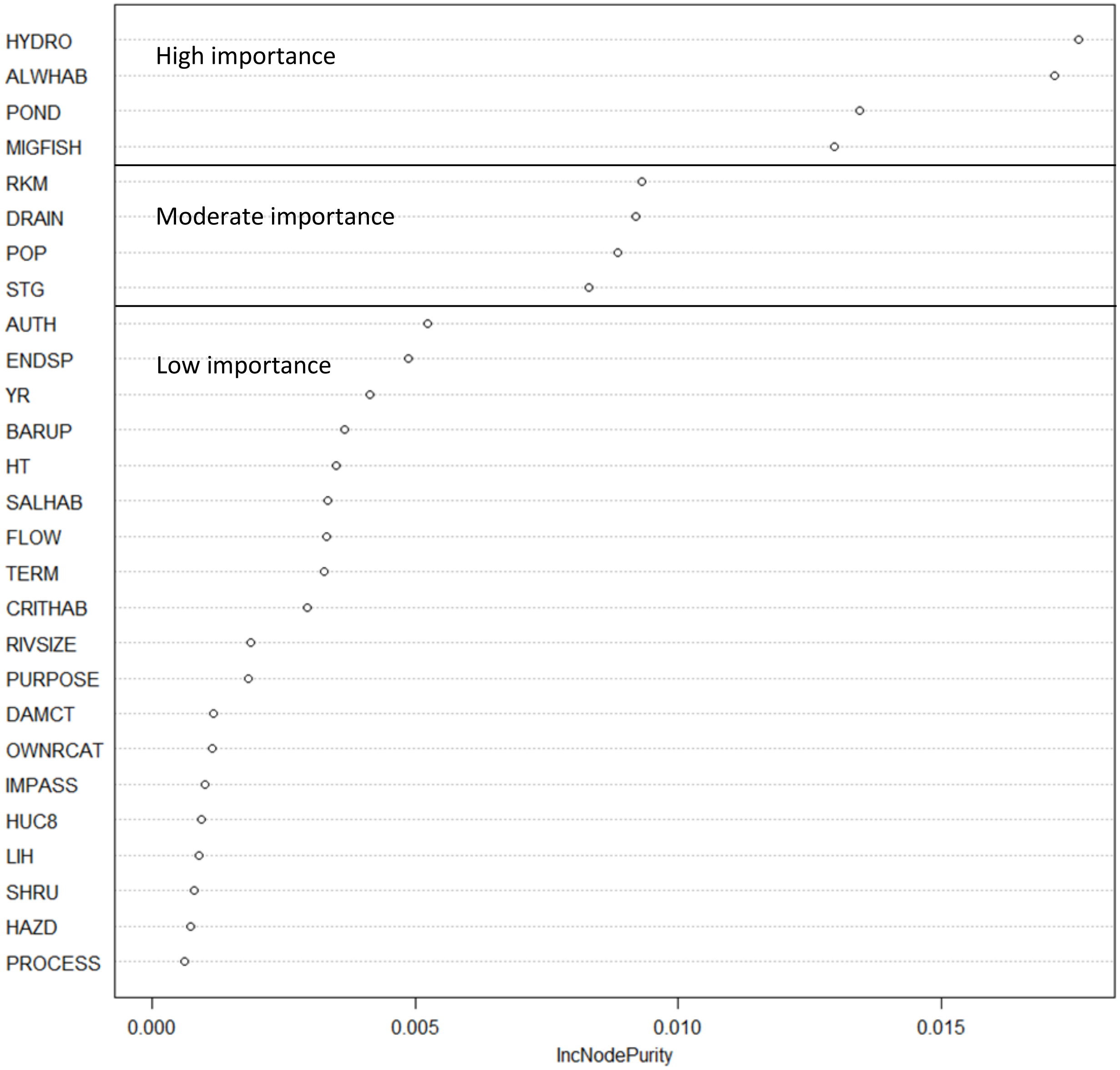


Figure 1.6. Random forest model. Model results showing the relative importance of project characteristics (n = 27; described in Table 1.2) for explaining variation in fish passage concern. The x-axis describes the increase in node purity (measured by the residual sum of squares) from splitting on a given variable, averaged over all decision trees. A high relative increase in node purity indicates high relative importance of a given variable in explaining variation.

Discussion

Temporal Trends

One major trend that emerged in our analysis of relicensing documents was a temporal "break" in relicensing patterns. Besides older licenses being shorter and less comprehensive than newer licenses, they exhibited lower levels of fish management, stakeholder engagement, and basin-scale planning prior to the 1990s (Table 1.1 & Figure 1.3). While licenses during this time period did typically include sections on recreation, cultural impacts, water quality, and environmental impacts, these were generally limited in scope. After the 1990s however, references to the conservation of certain fish species became apparent.

Atlantic salmon grew in importance for many projects in the Kennebec and Penobscot Rivers (Figure 1.3). This increase in focus can be partially attributed to the listing of the GOM DPS of Atlantic salmon in 2000 under the ESA though this did not include the Kennebec and Penobscot until 2009. The listing prompted projects in salmon Critical Habitat to develop plans for passage improvements (NOAA & USFWS, 2005) and granted protections for Atlantic salmon that are not shared by other species. Besides the stronger regulatory framework, Atlantic salmon are a generally *"likable"* species due to their high economic and cultural value. They elicit strong emotions and are popular, charismatic representatives for restoration and conservation goals (Kochalsi et al., 2018). This is demonstrated by active conservation campaigns for Atlantic salmon and their Pacific cousins (e.g., nativefishcoalition.org; wildsalmon.org; standforsalmon.org) and by numerous special interest groups dedicated to salmon recovery (e.g., Maine Rivers, Downeast Salmon Federation, Project SHARE, etc.). Fish passage measures are most often developed with Atlantic salmon passage in mind (Williams, 2012) and they receive substantial funding from public and private sources for their conservation (e.g., national hatchery support, state and federal agency support, NGO initiatives, etc.)

Similarly, American eel have grown as a species of concern at hydropower projects (Figure 1.3). They were considered for ESA listing in 2007 and 2015, but populations were found to be stable (80 FR 60834). Maine is currently the only state, besides South Carolina, that allows juvenile eels (elvers) to be caught, which supports a lucrative fishery (ASMFC, 2019). Despite reported population stability at low levels, concerns exist over the long-term sustainability of the fishery, given harvest-related crashes in European eel and Japanese eel populations. Moreover, upstream eel passage is generally more straightforward and cheaper to install than other types of fishways (Jellyman and Arai, 2016), making them logistically easier to address during relicensing.

Despite the presence of a variety of sea-run fish in the Kennebec and Penobscot Rivers (Houston et al., 2007), we found that other species are rarely referenced in licenses (Table 1.5). Mentions of American shad and river herring are consistently low over time in comparison to Atlantic salmon and American eel (Figure 1.3). This may be due to a reduced priority of these fish by federal and state agencies or the expectation that fish passage designed for Atlantic salmon will meet the needs of all species. Other species, such as sea lamprey are not mentioned at all, though they contribute valuable nutrients and habitat improvements to their environments (Weaver, 2016). Lack of attention to sea lamprey in license negotiations may be attributed to their negative image due to their impacts in areas they are not native to, and because they lack value as a commercial fishery. While it may not be a priority to allow passage for all fish species, a case can be made that integrated river management requires free movement of all fishery resources.

Irrespective of individual species, we found that overall references to fish passage increased in licenses over time (Figure 1.3). Increased concern over Atlantic salmon and American eel and changes in environmental regulations have made fish passage a priority concern for many resource agencies. Other mitigative terms such as fish stocking and conservation funding did not increase. Settlement agreements were largely absent from licenses prior to 2005 (Figure 1.3) and have only recently been embraced as a collaborative tool for stakeholders to negotiate license terms and conditions prior to relicensing proceedings. One limitation of tracking settlements in relation to the relicensing process, is that there is often a disconnect among project expiration dates and settlements may be achieved outside of the relicensing process. For example, the Lower Penobscot Settlement Agreement led to the removal of two dams and fish passage improvements at several projects in the Penobscot River (Opperman et al., 2011). Despite being highly influential, the agreement was not reflected in project licenses that were issued prior to the settlement in 1998 (Figure 1.3).

A temporal shift in relicensing was especially apparent in terms of the level of stakeholder engagement in relicensing decisions (Figure 1.3). Dam construction continued to increase in the 1970s and 1980s largely in response to U.S. Congressional incentive programs for hydropower development. However, despite the new legal framework and public concern for the environment in the 1980s, many regulations were not implemented immediately. In fact, the FPA was not modified until 1986 to require the balance of energy, recreational, and environmental concerns at hydropower dams (16 U.S.C § 797(e)) and NEPA was not formally implemented until 1987 (Richardson, 2000).

Generally, we found that resource agency participation and the corresponding invocation of authorities increased after the 1990s (Figure 1.3). This coincides with the instatement of the ILP as the default process in 2005, before which, the process was traditionally marked by latent FERC and stakeholder involvement. Additionally, several court rulings during this time supported resource agency authority in matters regarding environmental law (Daniel Pollak, 2007; Richardson, 2000). The WQC in particular, prompted numerous court cases that have clarified the boundaries of state authority after FERC rejected water quality conditions as “beyond the scope of state authority.” More recently licensed projects are required to incorporate all WQC conditions into licenses.

Spatial Trends

Another major trend that emerged from relicensing documents was a management gradient relative to project location (Figure 1.4). Coastal projects tend to occupy larger rivers, operate run-of-river flows, and host sea-run fish in the project's boundaries (Table 1.1). Conversely, inland projects are typically in smaller rivers, operate for water storage, have large impoundments, and have no historic sea-run fish habitat (Table 1.1). In our analysis, fish passage language strongly correlated to this gradient. Unsurprisingly (given the perceived importance of sea-run fish and an emphasis on Atlantic salmon conservation) we found that coastal projects referenced fish passage more often than those further inland (Figure 1.5). Several inland projects did not address fish passage at all. This was supported by our random forest analysis that identified the number of downstream hydropower projects, upstream alewife habitat, number of sea-run fish, and the presence of an impoundment as predictive of fish passage documentation in project licenses (Figure 1.6).

While statute and stakeholder license terms had relatively little predictive power (except for NOAA) in the NMDS, they did ordinate along the coastal-inland gradient. References to MDMR, NOAA, and USFWS clustered with coastal projects, while MDIFW clustered with inland projects (Figure 1.5). This is likely due to the specific authorities these agencies hold in relation to impacted resources. For example, MDMR and NOAA are specifically tasked with managing sea-run fish which are prevalent at coastal projects. Conversely, MDIFW is tasked with managing freshwater fish, terrestrial wildlife, and inland recreation. At times this duality may be a source of conflict where the needs of sea-run and freshwater fish clash. MDEP is a central figure at all projects due in part to their authority in administering WQC and managing water resources.

One common way to promote basin-scale management has been to coordinate license terms for projects in shared river basins. This generally includes accelerating or extending license terms to relicense related projects concurrently (Curtis and Buchanan, 2018). Using this rational, projects in proximity, especially those with the same licensee, may be synchronized. The FPA explicitly mandates the coordination of licensing terms for multiple projects in a river basin (18 C.F.R. § 4). We found several paired projects that were managed this way (e.g., Abenaki and Anson (2003); Automatic and Messalonskee (1999); and Penobscot Mills and Ripogenus (1996). However, this coordination of licensing terms did not extend to larger project groupings.

Several projects could be seen as employing basin-scale management with regard to the number of individual dams managed in a single license. For example, though licensed as a distinct project, Great Lakes Hydropower (2004) consists of a complex of nine storage dams over a broad area. Similarly, Penobscot Mills (1996) consists of five dams, Messalonskee (1999) consists of three, and Milford (1998), Moosehead Lake (1997), and Shawmut (1981) consists of two. These techniques in dam management however are not consistently applied across the Kennebec and Penobscot River watersheds. Despite a push towards basin-scale management and boiler plate references towards cumulative impacts, we found low levels co-management in project licenses as shown by our index (Table 1.2).

Beyond direct licensing decision-making, more comprehensive restoration actions have been observed through external influences. The Penobscot River Restoration Project is a good example of this. This project originated as a self-proclaimed *“public-private effort to maintain hydropower and restore sea-run fisheries on the Penobscot”* (NRCM, 2019). Terms and conditions derived from the project did influence project license amendments, however, the process itself was the result of arbitration and cooperation outside of FERC licensing (Opperman et al., 2011). These stakeholder-driven approaches may provide an avenue for negotiation and inclusion that is not possible within the bounds of the relicensing process.

Projects that were co-managed and geographically close to one another translated to similar project features, fish management concerns, and stakeholder objectives. This facilitated the coordination of licensing dates so that relicensing could be addressed at the same time, however, this did not hold true for all closely located projects. For example, the Orono (2005) license in the Penobscot River readily referenced Great Works (1963), Howland (1980), Stillwater (1998), Veazie (1998), and Milford Dams (1998) which are commonly addressed together in current conservation plans. The other projects, which were relicensed prior to the Lower Penobscot River Basin Comprehensive Settlement Accord in 2004, did not reference nearby projects. Similarly, Shawmut (1981), Benton Falls (1984), Hydro-Kennebec (1986), and Weston (1997), which were relicensed prior to the Lower Kennebec River Comprehensive Settlement in 1998, did not reference each other. Lockwood (2005), which was also part of the settlement, did mention the other projects.

Challenges and Opportunities for Integrative Basin-scale Management

Ongoing assessments of the declines of sea-run fish and the increasingly collaborative regulatory process, have led to the consideration of the cumulative impacts inherent of multiple dams in a river. It has been found that the potential for improving hydropower sustainability is higher when projects are managed beyond single project mitigation (Roy et al., 2018; Song et al., 2019). This has prompted a shift towards basin-scale planning of river systems (Neeson et al., 2014). Energy policy as such has evolved to require the assessment of cumulative impacts of multiple projects in order to manage the river and environmental concerns pursuant to federal and state comprehensive plans (16 U. S. C. § 10(a)(2)). Despite this, decision-making has been extremely site-specific.

Limitations are inherent to the long policy and management cycles typical of hydropower relicensing. While long license terms are meant to mitigate market uncertainty for licensees and manage resource use by regulatory agencies, they can make it difficult to effectively manage dynamic environmental resources (Thomas and Koontz, 2011). Rigid license terms, often prohibit substantial changes to hydropower operations outside of relicensing, making it difficult to coordinate and manage fish passage concerns among all the projects in the system. The existent network of projects with haphazard and uncoordinated licensing timeframes (Table 1.1), also makes it difficult to address basin-scale planning.

Passage standards for sea-run fish often necessitate their passage at projects lower in the system. Because license issuance is not necessarily dependent on location along the coastal to inland gradient, projects management is often mismatched in time. This may have the effect of stalling conservation measures. For example, fish passage provisions at the Hydro-Kennebec Project (1986) were deemed necessary but were only to be implemented after fish passage needs were met at the downstream project (Edwards, now removed). Fish passage was not further addressed until 1998 when the Lower Kennebec Settlement Agreement required planning for interim fish passage. This stipulated that permanent fish passage was not required until 2010 or until fish numbers reached a target goal at the Lockwood Project downstream. Most recently (2018), permanent fish passage designs have been approved, but construction has not been completed. Other projects in the Lower Kennebec River also exhibit this long timeframe.

The hydropower relicensing process is perhaps more collaborative now than it has ever been, as seen by the increase in agency participation and licensing authorities in the Kennebec and Penobscot Rivers (Figure 1.3). The relicensing process has become more complex and interdependent over time (Ansell and Gash, 2007) and research has suggested that this collaboration can directly improve environmental outcomes (Mandarano, 2008; Ulibarri, 2015). Successful collaborative basin-scale planning and assessments have occurred when federal agencies worked with state and local agencies, Native American Tribes, environmental groups, the hydropower industry, and other interested stakeholders to resolve issues regarding existing hydropower projects (Saulsbury et al., 2010).

Beyond the suite of federal (NOAA and USFWS) and state (MDNR, MDIFW, and MDEP) resource and regulatory agencies, other stakeholders are invited to participate in the relicensing. These include Tribal Governments, community members, and special interest groups. While our research did not explicitly examine these stakeholder groups, we acknowledge that their influence may significantly affect project outcomes. For example, the Penobscot Indian Nation, actively participates at projects within their lands in the Penobscot River. They contribute to meetings, manage conservation funding, and were instrumental in negotiating the Lower Penobscot River Settlement Agreement (NRCM, 2019). While all stakeholders may be able to participate through official comments and influence agency objectives as constituents, their ability to participate may vary depending on affiliation, time, human capital, and financial resources (Ulibarri, 2015). These efforts may not always be consistent. An opportunity for future research exists to investigate patterns of non-agency influence in relicensing to encourage equitable participation from stakeholders that may be currently underrepresented in relicensing.

Similarly, opportunity exists to facilitate passage for fish species currently underrepresented in management with the implementation of equitable passage facilities and standards. This requires the establishment of success standards for all fish species that have declines attributed to dams. For example, while the Milford Project must meet passage standards for Atlantic salmon, similar standards do not exist for other species. Furthermore, aggressive timelines for the construction of fish passage would benefit populations currently unable to access essential habitat. Holistic passage is expected to continue to be an issue in hydropower decision-making given that no perfect solution to pass all species and life stages has been discovered (Bunt et al., 2011; Noonan et al., 2012) beyond complete dam removal.

Given the expected increase in relicensing work in the next decade, benefit may be seen in updating basin comprehensive plans. While emphasis has been placed on coordinated and inclusive decision-making, comprehensive basin-wide assessments for the Kennebec and Penobscot River watersheds have not been addressed since the early 1990s. A synthesis of historic changes, existing studies, and objectives may also be useful for developing stakeholder understanding in future relicensing processes.

Limitations

Further exploration of documents beyond fish passage and outside of the relicensing timeframe could yield a more robust series of findings. Utilizing additional software and text analysis techniques will only serve to further this study. Similarly, consideration for the diverse stakeholder groups active during relicensing could uncover obscured themes and perceptions not captured here. Additionally, utilizing phenomenological methods on a smaller scale (e.g., case studies of select hydropower projects), may allow for a more nuanced understanding of the decision-making process. It is clear that the complexities of the relicensing process warrant in-depth and dynamic continued analysis.

CHAPTER 2

SCIENCE IN ACTION OR SCIENCE INACTION? EVALUATING THE IMPLEMENTATION OF "BEST AVAILABLE SCIENCE" IN HYDROPOWER RELICENSING

Abstract

Over the next two decades, half of all hydropower projects nationwide will require relicensing by FERC. During this time, agency regulators are tasked with using the "best available science" (BAS) to make informed decisions about hydropower operations and management. Although embraced as the standard, BAS is not well-defined. Focusing on the Kennebec and Penobscot River watersheds in Maine, citation analysis and an online stakeholder survey were used to identify the informational sources used in relicensing and assess agency perceptions of BAS. Analysis of relicensing documents (n=62) demonstrates that FERC and licensee documents are highly similar in citation composition. NOAA reports typically cite more sources and are three times more likely to cite peer-reviewed literature than FERC and licensee documents. Survey data reveals that federal and state agency respondents (n=49) rate peer-reviewed literature highly as in terms of BAS, followed by university, agency, and expert sources, while industry and community sources rate poorly. Overall, there is low agreement among survey respondents with regards to BAS rankings of informational sources. The reported differences in information use may be linked to disparities in the access to certain sources, particularly peer-reviewed literature. Enhanced understanding of information use may aid in identifying pathways for better informed relicensing decisions.

Introduction

Declines in migratory fish have been attributed to hydropower dams and resulting habitat fragmentation (Limburg and Waldman, 2009). These dams are sites of fish mortality (Maynard et al., 2018; Olden, 2015) and delay (Izzo et al., 2016; Nyqvist et al., 2017) for both upstream and downstream migration. Application of “safe, timely, and effective passage” standards (Turek et al., 2016) can be inconsistent and are generally negotiated on a case-by-case basis (FERC, 2017a). The Federal Energy Regulatory Commission (FERC), under the Federal Power Act (FPA), requires non-federal hydropower dam owners to obtain licenses for the operation and maintenance of their facilities (16 U.S.C. § 791 [a]). Licenses may be renewed every 30 to 50 years, providing a short window of opportunity for reassessing operations with respect to energy production, recreation, and environmental concerns (16 U.S.C. § 797 [e]). While license amendments may be made outside of this process, the relicensing period is the most efficient and productive time to influence operations related to flow rates, fish passage structures, and hydropower generation schedules (Kosnik, 2010).

In the next two decades, more than half of all active FERC-licensed projects (647 of 1,043) will require relicensing (Curtis and Buchanan, 2018). At the time of relicensing, federal and state resource agencies, Tribal Governments, dam licensees, and conservation organizations with different roles, responsibilities, and statutory obligations may provide input to the process. These include the issuance of Endangered Species Act (ESA) consultations (16 U.S.C. § 1531 et seq.), Water Quality Certifications (CWA; 33 U.S.C § 1251 et seq.), and Mandatory Conditioning Authorities (e.g., Departments of Interior and Commerce’s ability to impose fish passage prescriptions; 16 U.S.C. § 811). Balancing energy production and conservation goals can make decision-making complicated. The use of science to inform management is widely regarded as critical in policy decision-making (Holmes and Clark, 2008) and agencies are frequently required to draw on the “best available science” (BAS) to support regulatory decisions (Costa et al., 2016). Despite the importance of BAS, operationalizing the concept remains inconsistent and difficult to define (Costa et al., 2016; Murphy and Weiland, 2016). We sought to explore how information is used and valued by stakeholders in the FERC relicensing process. To do this, we used citation analysis and a stakeholder survey to characterize information use by FERC, licensees, and both federal and state resource agencies for dams in two Maine watersheds, the Kennebec and

Penobscot Rivers. This paper describes the use of science in hydropower relicensing policy. First, we outline the regulatory and policy context for relicensing decisions. Then we identify and assess agency perceptions of BAS using citation analysis and stakeholder survey methods and present out results. We conclude with implications of our findings on the decision-making process for hydropower relicensing.

Science as a Basis for Hydropower Relicensing Policy

The use of BAS to inform decision-making is codified in laws that influence and govern the relicensing process. The ESA provides the means for identifying threatened or endangered species and grants regulatory authority to the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA) for species protection (Murphy and Weiland, 2016). This was one of the first laws to stipulate that the "*best scientific and commercial data available*," be used in decision-making. The ESA's standard for BAS has been widely emulated by other federal and state laws (Murphy and Weiland, 2016) such as the Magnuson-Stevens Act (MSA), enacted to ensure that national fishery conservation and management was based on "*the best scientific information available*" (16 U.S.C. § 1801). Likewise, the U.S. Environmental Protection Agency (EPA) has emphasized the role of BAS in implementing the Clean Water Act (CWA) through Water Quality Certifications (Sullivan et al., 2006) and has prioritized "*refocusing the EPA's robust research and scientific analysis to inform policy making*" (US EPA, 2018, p 42).

The ESA, MSA, and CWA provide a regulatory framework for dam operation and management decisions that places emphasis on the importance of BAS in relicensing decisions. When federally endangered or threatened species are present near projects, ESA consultation ensures that "*actions are not likely to jeopardize the continued existence of the species...*" (16 U.S.C. § 1536). If a project affects the species, USFWS or NOAA must prepare a Biological Opinion that presents potential impacts, reasonable and prudent measures to minimize impacts, and license terms and conditions (FERC, 2001). Conditions may include flow prescriptions, operation management, and fishway installation.

Biological Opinions strongly influence relicensing decisions making it "*unlikely that we [FERC] will act in a manner that is inconsistent with the conditions of a Biological Opinion*" (166 FERC ¶ 61,030). Similarly, the MSA requires FERC to consult with NOAA on actions thought to impact Fishery Conservation and Management Plans and Essential Fish Habitat (EFH) for diadromous fish. NOAA is compelled by the MSA to establish overarching agency guidelines to address BAS and is explicitly required to invoke BAS (50 C.F.R. § 600.315). In addition, the CWA and relevant state laws give state agencies authority to impose mandatory terms and conditions (e.g., flow, oxygen, and temperature limits) to the project license (33 U.S.C. § 1341).

FERC communicates a high value for BAS, stating "*the finding of the Commission as to the facts, if supported by substantial evidence, shall be conclusive*" (16 U.S.C. § 8751). In practice, however, the application of BAS varies, in part, because of the inconsistencies in regulatory scope of BAS mandates. There are no laws that *explicitly* require FERC to consider BAS in their own decision-making. Additionally, BAS is not consistently defined. Decision-making has largely relied on independent reports by the National Research Council of National Academies (NRC, 2004) and the American Fisheries Society (Sullivan et al., 2006). These reports informed the updated 2013 MSA Provisions (National Standard 2; NS2) which outlines standards for scientific peer review and provides guidance on what constitutes BAS for fisheries management (50 C.F.R. § 600.315). The NS2, stresses the importance of following a research plan with a clear statement of objectives, conceptual model, study design, documentation of methods, results, and conclusions, peer review as appropriate, and communication of findings (16 U.S.C. § 1851). It promotes the "*widely accepted criteria for evaluating BAS: relevance, inclusiveness, objectivity, transparency, timeliness, verification, validation, and peer review of fishery management information as appropriate*" (16 U.S.C. § 1851). However, the standards also caution that, "*an overly prescriptive definition of BAS should be avoided due to the dynamic nature of science*" (78 FR 43066). As a term, BAS seems relatively straight forward. In practice, however, application of BAS is more difficult and, at best, inconsistent. This research seeks to clarify the concept and inform more effective use of BAS in hydropower relicensing decisions.

Study Area: Kennebec and Penobscot River Watersheds

The Kennebec and Penobscot River watersheds in Maine provide an ideal opportunity for studying BAS in the relicensing process. Within the next 20 years, 40 hydropower projects in Maine will require relicensing, the fifth highest in the nation, necessitating increased participation from federal and state resource agency stakeholders (Curtis and Buchanan, 2018). The Penobscot River is the second largest river in New England, and combined with the Kennebec River, the two watersheds drain more than 40 percent of the state by area. Both rivers were of high importance in the nineteenth century for the transport of timber and paper production (Gibson, 2017). Dam construction decimated many economically and culturally important fisheries in the 19th century (Hall and Jennings, 2010; Poff et al., 2007).

Both rivers retain populations of Atlantic salmon (*Salmo salar*), of which the Gulf of Maine Distinct Population Segment (GOM DPS) is listed as federally endangered (65 FR 69459) and returns remain low (NASCO, 2019). The federally endangered shortnose sturgeon (*Acipenser brevirostrum*) and the threatened GOM DPS of Atlantic sturgeon (*A. oxyrinchus oxyrinchus*) both occupy the tidal waters (78 FR 69310; 32 FR 4001). Additionally, alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*) are candidate species for ESA listing in the region. American eel (*Anguilla rostrata*) has been considered for listing twice in the past. Recovering these populations has become a top priority for managing agencies.

Several noteworthy changes to these river systems have occurred. In 1997, FERC ordered the removal of the Edwards Dam on the Kennebec River, the first federally-ordered dam removal against the wishes of a licensee. FERC ruled that the benefits of a free-flowing river outweighed the benefits provided by the dam, opening 30 km of habitat and eliciting other improvements to fish passage, including several other dam removals. The Penobscot River Restoration Project in 1999 was a collaborative effort to balance fish restoration and hydropower production interests that included conservation organizations, state and federal resource agencies, and three licensees. A major outcome of the PRRP was the removal of two hydropower dams and increased fish passage at another, improving access to 3,200 km of open river (Opperman et al., 2011). Decisions in this system (e.g., restoration focus, habitat improvements, fish passage implementation, etc.) consistently invoke the ESA and associated standards of BAS making it important to understand information use, perceptions of BAS, and knowledge gaps going forward.

Citation Analysis

Methods

We used citation analysis in tandem with an online stakeholder survey. This mixed methods approach followed a convergent, parallel design included both qualitative and quantitative aspects that allowed for more generalizable conclusions and compensated for the limitations of using a single method (Creswell and Plano Clark, 2011). Citation analysis has been effectively used to compare information use between stakeholders (Meho, 2016.) and to quantify BAS in ESA implementation (Lowell and Kelly, 2016). Building off this work, we used the references present in relicensing documents to understand how scientific information is applied in relicensing. Stakeholders with longer bibliographies, a more diverse use of citations, and comparatively more peer-reviewed sources would be more aligned with commonly held ideals of BAS (Lowell and Kelly, 2016). Similarly, we assumed that stakeholders closely aligned in management would exhibit similar citation profiles with one another.

Citation analysis was followed by an on-line survey for which we developed criteria to evaluate agency perceptions of informational sources as BAS. Drawing guidance from the NRC, AFS, and NS2, we identified five testable components of BAS: i) relevance (appropriate to the current time period and circumstances), ii) comprehensiveness (complete and inclusive), iii) objectivity (impartial and unbiased),

iv) transparency (clear and the approach to data collection understandable with the ability for validation and verification), and v) availability (easily obtainable and accessible). These concepts informed the survey design and allowed for the comparison of individual perceptions with the actual use of informational sources.

Active FERC-regulated hydropower projects in the Kennebec and Penobscot River watersheds which were granted new licenses or underwent license amendments from 2000 to 2018 were included in our analysis. These documents were readily accessible through the FERC eLibrary and licensing requirements were generally similar across projects. Relicensing documents analyzed include: i) Pre-Application Documents (PAD), ii) study plans and reports (SP&R), iii) Biological Assessments (BA), iv) and applications for new licenses authored by the licensee; v) Biological Opinions (BIOP) and v) mandatory conditioning license prescriptions (MCLP) that are authored by NOAA, and vi) Environmental Assessments (EA), vii) Scoping Documents (SD), and viii) official orders that are authored by FERC (FERC, 2017b; Supplement 1). We used the citations from these documents as an indication of information deemed important by document authors (Ding et al., 2018). Though our research focused on the relicensing process, several amendment documents were included, the most notable relating to the expansion of the ESA to include Atlantic salmon in the Penobscot River in the Gulf of Maine Distinct Population Segment. This change prompted the creation of documents analogous to the technical relicensing process.

Documents were obtained from the FERC eLibrary. Text searches were performed to isolate process-specific documents that were mandatory or common according to the FPA (16 U.S.C. § 791) and the FERC Hydropower Primer (FERC, 2017b). Many stakeholders, including state and tribal entities, actively participated in the relicensing process. Project licensees, NOAA, and FERC had the primary responsibility for generating relicensing documents such as PAD, SP&Rs, BIOPs, MCLPs, EAs, and SDs. These documents, dated 2008 and later, were downloaded in Portable Document Format (PDF) with computer recognizable text elements. Documents dated prior to 2008 were downloaded as plain text (.txt), Microsoft Documents (.doc), or raster graphics (.jpg) and transformed into searchable PDFs using Optical Character Recognition software (ABBYY FineReader 14, ABBYY, Milpitas, CA 95035).

Our initial selection was 133 reference documents from 31 hydropower projects in the Kennebec and Penobscot River watersheds. Draft documents were excluded from analysis unless a final document was unavailable as well as small-scale, focused study reports containing few to no citations. Our final sample consisted of 62 documents central to relicensing. They included: licensee PADs (n=5), SP&Rs (n=15), BAs (n=7), and applications for new licenses (n=11); NOAA BIOPs (n=8); and FERC EAs (n=16). All documents included site-specific information (e.g., physical characteristics, regulatory histories, current state of knowledge, proposed operational changes, and potential impediments to relicensing). They included in-text citations and "*reference*" sections with which licensees, NOAA, and FERC supported their viewpoints and decisions.

From these selected documents, references were extracted into a citation database with their year and source identified. These documents were categorized into seven groups: academic, federal, state, FERC, licensee, peer-reviewed, and "*other*" (*sensu* Jennings and Hall, 2012; Lowell and Kelly, 2016; Table 2.1). A distinction was made between peer-reviewed publications (i.e., scholarly journals and books) and documents that reported "internal peer review". Academic citations included student theses/dissertations, general documents (e.g., maps), books from a University Press, and documents produced by USGS Cooperative Fish and Wildlife Research Units. Federal citations included those produced by any federal agency (foreign or domestic), consisting primarily of NOAA documents. State citations included all state agency documents (e.g., Maine Department of Marine Resources (MDMR), Inland Fisheries and Wildlife (MIFW), and Environmental Protection (MDEP)). FERC citations included all FERC correspondences (generally as official orders). Licensee citations included correspondence, plans, and reports produced directly by the licensee (by contracted consultants). Other citations included NGO publications, international and mixed governance organizations, presentations, personal communications, history books, general knowledge books, and textbooks.

A one-way ANOVA was used to compare the number of citations per document by author and a Tukey post-hoc test was used for pairwise comparisons if a difference was detected. Chi-square tests were used to compare the proportions of different sources used between licensee, NOAA, and FERC authors with z-tests determining significance between paired items. Relative proportions of citation categories were used to construct citation profiles for each stakeholder. The age of citations (at time of document preparation) was compared among groups to assess use of recent information. “Highly influential citations” were identified by widespread use in more than a quarter of the documents (Supplement 2). An α value of 0.05 was adopted for all tests.

Table 2.1. Informational sources. These sources are typically used by stakeholders for information gathering in the hydropower relicensing process. The relative use and value of these sources was investigated using a citation analysis of relicensing documents and a stakeholder survey.

Source of information	**Information format or genre:**
Academic	Theses, dissertations, general resources, USGS Cooperative Research Unit documents, University Press books
State Agency *Broadly termed "agency" in stakeholder survey, along with federal sources*	Reports, studies, general documents not published in traditional peer-reviewed formats (agencies may still apply internal peer-review)
Federal Agency *Broadly termed "agency" in stakeholder survey, along with state sources*	Reports, studies, general documents not published in traditional peer-reviewed formats (agencies may still apply internal peer-review)
Licensee/industry	Correspondences, reports, plans, studies from licensees and contracted consultants
Peer-reviewed publications	Journal articles, edited books compiled by professional organizations
FERC (*Not included in stakeholder survey)*	Correspondences, requests, official orders
Other (*Not included in stakeholder survey)*	NGO publications, history-, general knowledge-, and text-books, international and mixed governance organizations, presentations, personal communications
Community (*Not included in citation analysis)*	Community comments, personal interactions
Expert (*Not included in citation analysis)*	Professional advice, personal interactions

Results

Among the 62 analyzed documents, a total of 5,044 individual citations were identified. The average number of citations was 47.5 per document (IQR = 19.5-121.75). Citations could be attributed to academic (5.5%), federal (19.8%), state (20.8%), FERC (2.9%), licensee (13.0%), peer-reviewed (27.4%), and other (10.5%) sources (Table 2.2). NOAA documents (n=8) cited more sources than FERC (n = 16) and licensee (n = 38) documents (211.5, IQR = 122.5-305.75; 28, IQR = 17.5-63; and 43, IQR = 17.5-113, respectively; Table 2.2 and Figure 2.1).

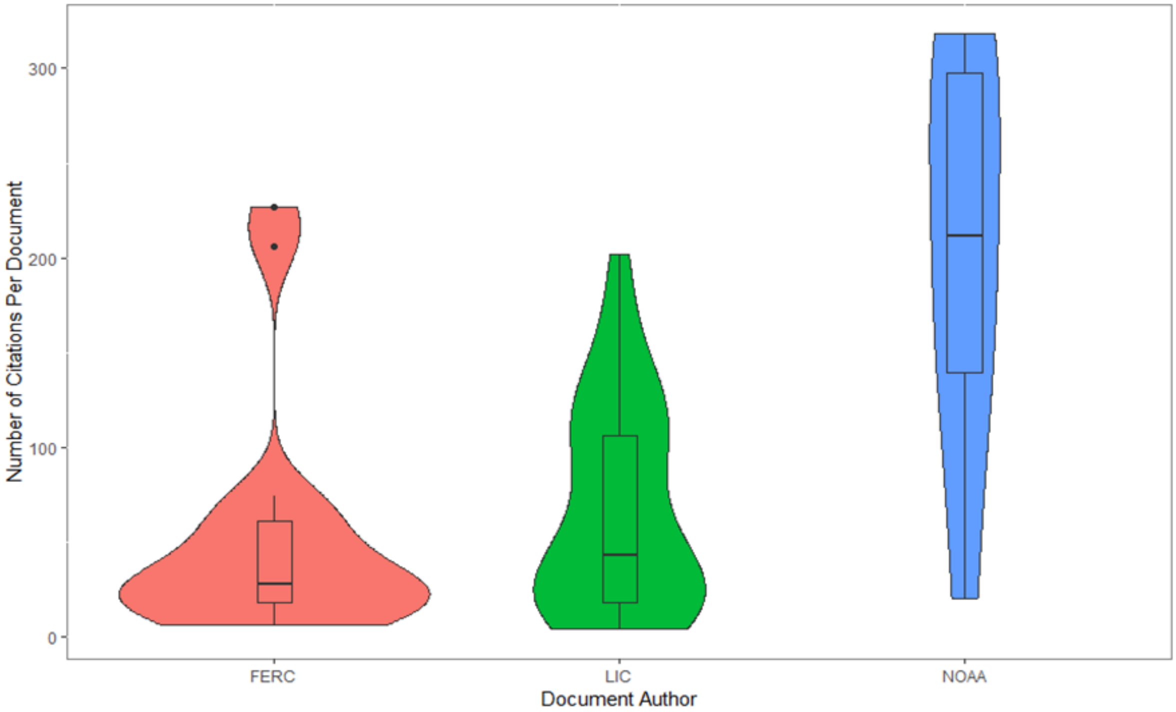


Figure 2.1. Citations per document. Violin plots visualizing the average number of citations per hydropower licensing document derived from the Kennebec and Penobscot Rivers, Maine from 2000-2018. Citations are stratified by document author (FERC, Licensees, and NOAA). Mean, 95% CI, and SD are indicated by internal box plots.

Table 2.2. Citation analysis summary. Summary statistics for citations found in hydropower relicensing documents from projects in the Kennebec and Penobscot Rivers, Maine, from 2000-2018. Citations were categorized by informational source (federal, FERC, licensee, other, peer-review, state, and academic) as cited by NOAA Fisheries, FERC, and Licensee authors. Each subscript letter denotes a subset of author categories whose column proportions do not differ significantly from each other at the 0.05 level.

	NOAA	**FERC**	**Licensee**	**Total**
Document count	8	17	37	62
Citation count	1626	915	2503	5044
Citation median per document	211.5	28	43	47.5
Citation interquartile range	122.5-305.8	17.5-6	17.5-113	19.5-121.8
Citations by source, % *(n)*				
Federal	20.1 (*327*)$_{a}$	20.0 (*183*)$_{a}$	19.6 (*491*)$_{a}$	19.8 (*1001*)
FERC	0.9 (*14*)$_{a}$	3.5 (*32*)$_{b}$	4.1 (*102*)$_{b}$	2.9 (*148*)
Licensee	6.9 (*113*)$_{a}$	16.5 (*151*)$_{b}$	15.7 (*392*)$_{b}$	13.0 (*656*)
Other	5.5 (*89*)$_{a}$	15.4 (*141*)$_{b}$	11.9 (*299*)$_{c}$	10.5 (*529*)
Peer-review	50.4 (*820*)$_{a}$	17.2 (*157*)$_{b}$	16.1 (*403*)$_{b}$	27.4 (*1380*)
State	9.7 (*158*)$_{a}$	23.7 (*217*)$_{b}$	27.0 (*676*)$_{b}$	20.8 (*1051*)
Academic	6.5 (*105*)$_{a}$	3.7 (*34*)$_{b}$	5.6 (*140*)$_{a,b}$	5.5 (*279*)

The use of information sources was found to differ by document author (x^2 (12) = 790.2, p = 0.001, φ = 0.280). FERC and licensee citations showed no difference in their proportional use of six out of seven informational sources and were evenly distributed across state (23.7/27.0%), federal (20.0/19.6%), peer-reviewed (17.2/16.1%), licensee (16.5/15.7%), and other (15.4/11.9%) sources. Low proportions of academic (3.7/5.6%) and FERC (3.5/4.1%) sources were used (Table 2.2). NOAA citations differed from FERC and licensee citations and were primarily of peer-reviewed sources (50.4%) and federal references (20.1%). Low proportions of state (9.7%), licensee (6.9%), academic (6.5%), other (5.5%), and FERC (0.9%) sources were used (Table 2.2).

Citation publication year ranged from 1825 to 2017 and were 0 to 177 years old with respect to the document they were cited in (Figure 2). Citations averaged 14.7 years old and differed among authors (one-way ANOVA, F = 37.9, p = 0.001). A Tukey post-hoc test revealed (p = 0.001) that NOAA citations are 4-5 years older than FERC and licensee documents (17.9 ± 16.1, 12.5 ± 18.1, and 13.5 ± 19.0, years respectively)). There was no difference between the age of citations from FERC and licensee authors (*p* = 0.288).

On average, individual references were cited in at least three documents (mean = 3.8 ± 3.71). Three quarters of all citations were used five times or fewer and 37.7% were used only once. Seven sources were cited in 15 or more documents (Supplement 2). These documents were mainly technical documents related to the decline, conservation efforts, and status of Atlantic Salmon.

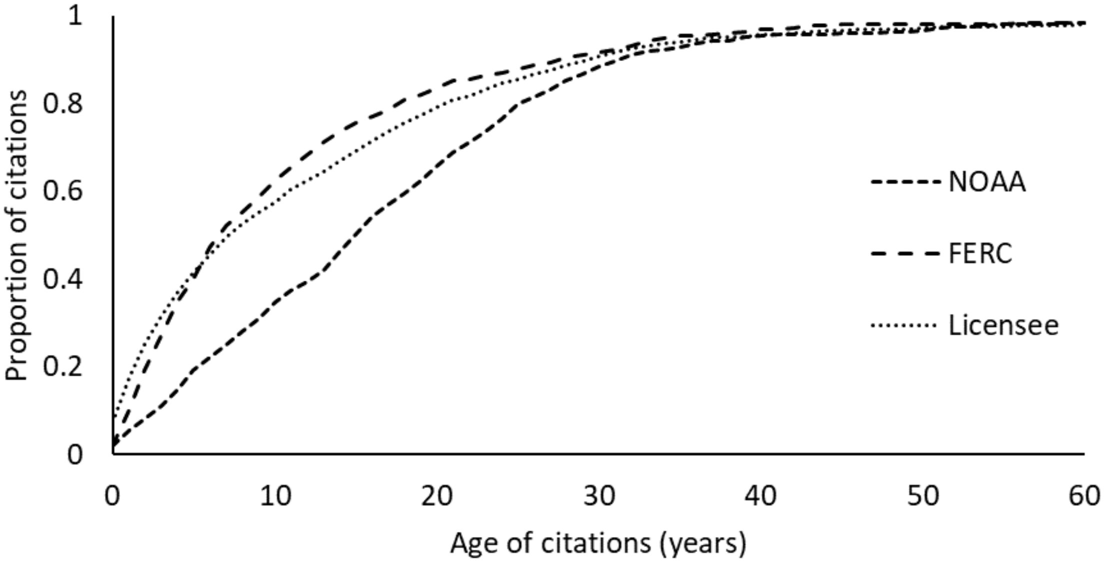


Figure 2.2. Citation age. Relative age of the citations used by NOAA Fisheries, FERC, and licensee authors in hydropower relicensing documents.

Stakeholder Survey

Methods

We used a non-proportional, purposive sampling (Etikan et al., 2016; Lavrarkas, 2008), to characterize how federal and state resource agencies define and operationalize BAS. We used an online survey which invited participation from individuals from agencies involved in the regional relicensing process (NOAA, USFWS, MDEP, MIFW, MDMR). While our citation analysis did not include State of Maine-authored documents, State agency members have specific influence in the relicensing process related to water quality certification and fishery management. Penobscot Nation resource agency members and some licensees were also invited to participate (Lavrarkas, 2008) but were not included in our final analysis due to their small sample size and unstructured sampling.

Survey participants were identified by i) having demonstrated authority in the relicensing process (e.g., listed as a mandatory contact in FERC eLibrary documents), ii) having been identified as participants by those with authority (*sensu* Gilchrist and Williams, 2009), iii) through informal contacts (e.g., participation at scoping meetings, fisheries conferences, and public forums), and iv) being listed in agency directories as having relicensing responsibilities. Survey respondents were asked to identify other key people (snowball technique; Lavrarkas, 2008) but no additional participants were identified.

The survey consisted of multiple choice (n=6), open-ended (n=8), and ranking (n=11) questions (Supplement 3). Participants reported their organization, job title, and years of experience in the relicensing process. They were asked a series of questions as to the frequency of participation in common relicensing tasks (5-point Likert scale from "*do not participate*" to "*frequently participate*"). Tasks included: FERC document review, scoping meetings, study design planning, scientific evaluation and synthesis, coordination with other entities, providing official written comments, task force/committee participation, and whether they held a supervisory role. Similarly, they were asked to identify how frequently they invoked common skills and expertise (5-point Likert scale from "*do not* *emplo*y" to "*frequently employ*"). Skills included: fisheries, engineering (including fish passage), hydrology, policy, communication, negotiation/mediation, and community engagement. Participants were invited to identify additional tasks or skills not included in the survey.

The open-ended question, "*In your opinion, what constitutes best available science*?" was used to collect respondents' view of BAS. Participants were asked to rate informational sources (i.e., unpublished academic research (e.g., theses), agency grey literature, industry reports, community comments, peer-reviewed publications, and expert opinion) based on their perception of the defined BAS metrics (*relevance, comprehensiveness, objectivity, transparency, and availability*) on a 5-point Likert scale ("not relevant" to "extremely relevant"). Community comments (e.g., comments from community members not affiliated with federal and state agencies) and expert opinion (e.g. advice and information provided by key informants) were addressed through the survey in order to gage respondents' perceptions of personal interactions that could not be investigated through citation analysis. The BAS metrics were used to calculate an index (mean value of these five metrics) for each source. Frequency of use for each source was also assessed (5-point Likert scale, "*do not use*" to" *frequently use*"). Two open-ended questions, "*What do you consider the main strengths of the sources you use?*" and "*What type of information would be beneficial to have but is currently unavailable to you?*" were used to assess what information participants found important.

Because of the routine use of email by our invited population, the questionnaire was administered with Qualtrics web-based software (Qualtrics, Provo, UT). We implemented our survey using the Tailored Design Method (Dillman Method) to increase trust, perception of reward, and to minimize costs and time burden for respondents thereby reducing survey error (Dillman et al., 2014). The survey was pilot tested with "*knowledgeable colleagues*" to identify omissions or redundancies (Dillman et al., 2014). Pilot study participants were asked to assess the ease and length of the survey;

general comments were invited. Major deficiencies were not identified and only minor changes in formatting were implemented for the final version.

A pre-survey letter was sent (by both mail and email) to inform invited participants and ask for their help. A subsequent email to participants included a personal survey link. A series of reminder emails (after one and two weeks) were sent to improve our response rate (Dillman et al., 2014; Van Mol, 2017). During this time there was a partial federal government shutdown, limiting federal employee participation (and some state partners). To accommodate these participants, a final email was sent eight weeks later to all non-respondents and those that partially completed the survey.

Of 99 initial invited people, 56 completed the survey (initial response rate of 56.6%). Six respondents expressed that they had no affiliation with Maine or relicensing and were removed from the pool. Two invited people had incorrect contact information did not receive the survey. An additional nine individuals were convenience sampled (licensee and tribal stakeholders) and were not included in our analysis. This brought the possible effective sample size to 82. Three individuals opted out of the survey and 30 did not respond or did not finish the survey resulting in 49 participants (59.7 % response rate) for our final analysis.

We compared federal and state agency responses across each of the BAS items using t-tests. Differences within federal and state groups were examined using the Potential for Conflict Index$_2$ (PCI; Vaske et al., 2010). The PCI$_2$ assesses variation in response within a group as well as the central tendency and ranges from zero (perfect consensus among respondents and no potential for conflict) to one (no consensus and a high potential for conflict). Statistical differences (*d*) tests were assessed as described by Vaske et al. (2010).

We used deductive coding to characterize responses to open-ended questions. The question, "*In your opinion, what constitutes best available science?*" was compared to measurements of the perceived relevance, comprehensiveness, objectivity, transparency, and availability of different sources of information (e.g., "*not relevant*" - "*extremely relevant*," 5-point Likert scale). This was further compared to the self-reported use of those sources (e.g., "*do not use*" – "*frequently use*," 5-point Likert scale). The open-ended questions, "*What do you consider the main strengths of the sources you use?*" and "*What type of information would be beneficial to have but is currently unavailable to you?*" provided further insight into what information participants found personally important.

Results

The 49 analyzed participants included a balanced response from state (n=24) and federal (n=25) stakeholders. Federal respondents included USFWS (32%) and NOAA (68%) employees; state respondents included employees from MDEP (16.7%), MDIFW (45.8%), MDMR (33.3%), and Maine Bureau of Parks and Lands (4.2%). Collectively, respondents indicated a high degree of relicensing experience with 77.6% indicating more than five years of experience. Several respondents identified additional relicensing responsibilities related to public communication, conflict resolution, and monitoring post-licensing mandates. Respondents reported a high use of fisheries expertise, policy expertise, and communication skills. Additional expertise and skills included data management and analysis, engagement with Tribal Governments, and balancing community needs. Tasks relating to relicensing were not the primary job function of most respondents. With few exceptions, most individuals assumed relicensing responsibilities in addition to their other organizational responsibilities.

Informational sources were rated by respondents in terms of the five BAS metrics previously identified from literature and a BAS index calculated for each respondent. In general, respondents rated peer-reviewed, academic, agency, and expert sources high in terms of BAS while industry and community sources were rated low (Figure 2.3 and Table 2.3). Peer-reviewed and academic sources received a higher BAS score from federal respondents ($p < .001$; Table 2.3). Conversely, expert sources received a higher BAS score from state respondents ($p < .05$). There was no difference in the perceptions of agency-, industry-, or community-produced information. Consensus between respondents was consistently high among groups (federal = PCI_2 0.38-0.58; state = PCI_2 0.43-0.56). While there was higher consensus among state respondents regarding industry sources ($p < .05$; Table 2.3), the remaining five sources did not show a difference.

Table 2.3. Best available science index. Differences in the perceptions of best available science and use of six informational sources used by federal and state resource agency survey respondents.

	Resources Agency			
	Federal (51%)	**State (49%)**	***p***	***eta***
	Perceptions of best available science by informational sources			
Academic	3.6	3.1	0.006	0.390**
Agency	3.5	3.5	0.949	0.009
Industry	2.7	2.8	0.519	0.095
Peer-reviewed journals	4.4	3.9	0.004	0.405**
Expert opinion	3.5	3.9	0.034	0.307*
Community comments	2.4	2.6	0.185	0.195
	Self-reported use of informational sources			
Academic	3.6	1.9	0.001	0.634**
Agency	3.7	3.4	0.351	0.138
Industry	2.8	2.9	0.809	0.036
Peer-reviewed journals	4.5	3.6	0.008	0.377**
Expert opinion	3.5	4.1	0.055	0.279
Community comments	2.2	2.7	0.091	0.247

* significant p < 0.05
** significant p < 0.001

The use of different informational sources was self-reported by survey respondents. Collectively, sources that were rated higher in BAS by stakeholder groups were used more frequently than those which were rated lower. Federal respondents reported using peer-reviewed and academic sources more often than state respondents (*p* < .001; Table 2.3). Conversely, state respondents reported using expert sources more often (*p* < .05; Table 2.3). There was no difference in the use of agency-, industry-, or community-produced information. PCI_2 values ranged from 0.41 to 0.75 for federal respondents and 0.39 to 0.56 for state respondents (Figure 2.3). Differences in PCI_2 values were observed only in regard to industry sources (*p* < .05), for which state respondents reported using this source more similarly than federal respondents.

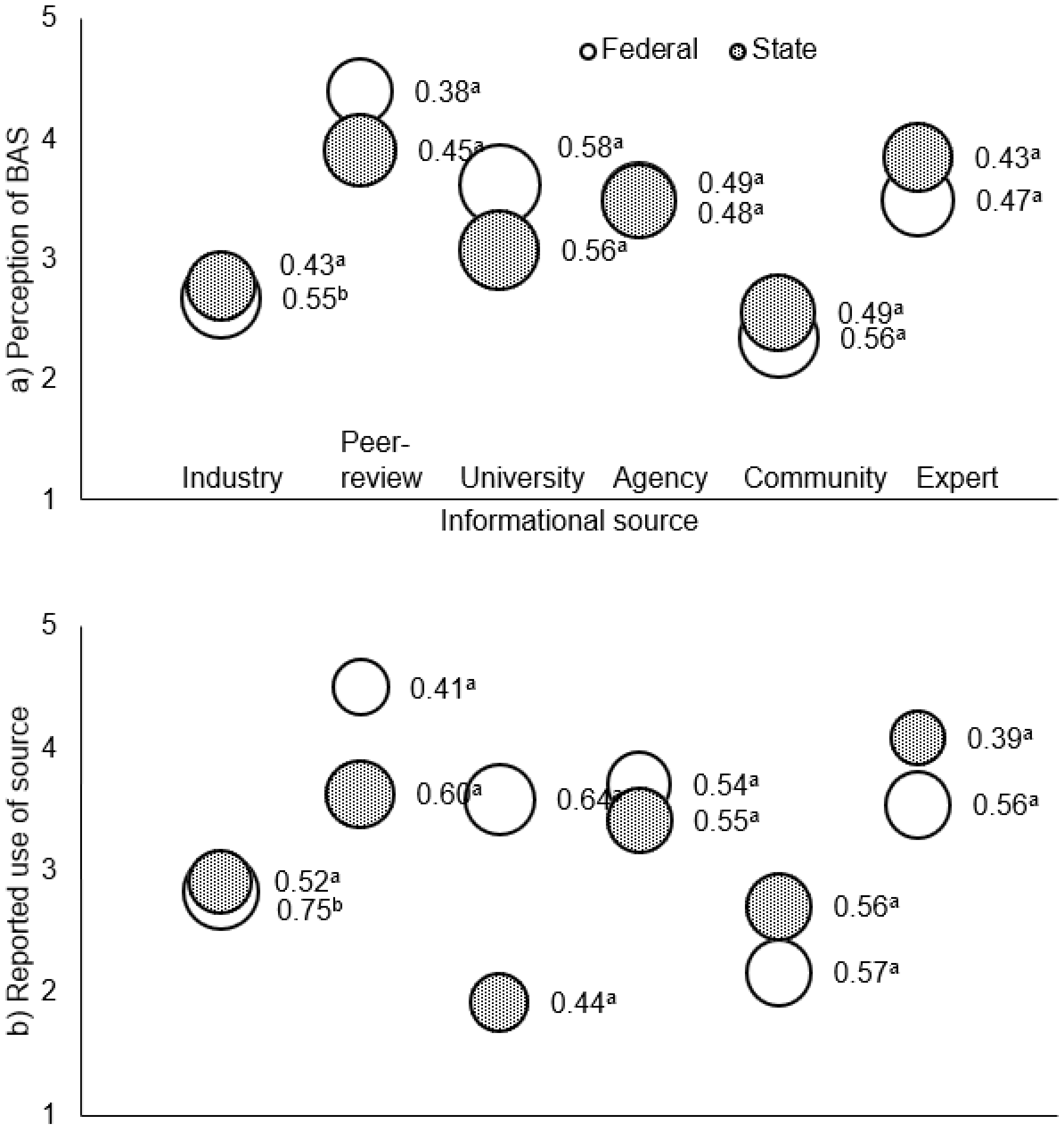


Figure 2.3. Perceptions and use of best available science. BAS Index rankings of six informational sources in terms of (a) perceptions of BAS compared to (b) their reported use by federal and state resource agency survey respondents. The middle of each bubble represents the mean response. The size and numbers listed for each bubble represent the PCI2 value. The superscript letters indicate statistical differences at $p < 0.05$. PCI2 values range from zero to one, indicating complete consensus to no consensus.

All respondents provided written answers for the question, “*what constitutes best available science?*” Respondents consistently affirmed relevance, comprehensiveness, objectivity, transparency, and availability as important factors. For example, one respondent confirmed the importance of, *“findings that are recent enough, on a study subject similar enough, in a study location similar enough, and carried out in a thorough and competent enough manner to be **relevant**.”* Another stated that best available science equated to information that was, *“defendable [with] any caveats/biases acknowledged/explained and put into context”* (**objectivity**). Others highlighted the importance of *“publicly **available**”* and *“published”* information. The accuracy of information by group consensus and professional judgement was also highly valued. Greater than half of the respondents specifically highlighted peer-review as being representative of BAS. One respondent stated, “*peer-reviewed publications have gone through an expert review, so the results are the most trustworthy*.” However, several respondents highlighted the uncertainty inherent to BAS: “*peer-reviewed papers are the gold standard, but there are lots of issues and questions that we must address for which the science has not yet sic[been] addressed*.”

Conclusions and Policy Implications

We found considerable variation in the informational sources that NOAA, the licensee, and FERC stakeholders consult during relicensing. NOAA documents use more citations than FERC and licensee documents and draw more deeply from peer-reviewed literature, suggesting a close alignment with traditional perceptions of BAS (Table 2.2). This is supported by a review of ESA decisions that found that NOAA exceeded USFWS in three of seven metrics related to BAS with no difference found for the remaining metrics (Lowell and Kelly, 2016). Generally, longer bibliographies, more diverse use of citations, and comparatively more peer-reviewed sources are seen as indicators for the use of BAS (Lowell and Kelly, 2016; Meho, 2006). The prevalence of these indicators in NOAA documents may be largely influenced by the direct regulatory guidance provided by the MSA, NS2 for fishery management.

Additionally, guidance is provided on what constitutes BAS, standards for peer review, and governance for the review of scientific information. In this way, NOAA is obligated to adhere to BAS standards in ways that other stakeholders may not.

FERC and licensee citation profiles were found to be similar in their proportional use of sources (Table 2.2) and citation age (Figure 2.2), possibly indicating a close alignment in management goals and decision-making styles. Alternately, the similarity could be a result of the regulatory burden and regional scope that FERC staff operate under to gather information. High workloads coupled with unfamiliarity with project sites may compel FERC staff to rely heavily on the submitted information from the licensee and other stakeholders. The licensee sets the stage with the PAD in providing FERC and other stakeholders with existing, relevant, and reasonably available information on the project. From this it is anticipated that stakeholders can identify issues and information needs, develop study requests and plans, and prepare for relicensing (18 CFR SS 5.6). The PAD also serves as a precursor to successive environmental assessments, including the scoping documents, environmental impact statements, or environmental assessments produced by FERC.

The licensee sets the foundation in the process. This process of “anchoring expectations” can have unintended consequences for the types of information considered by FERC (Furnham and Boo, 2011). The relicensing process establishes terms and conditions of continued operations and stakeholders may recommend certain changes. This initial information, provided by the licensee, may bias expectations and subconsciously guide future negotiations toward this initial view at the cost of other issues and priorities. Anchoring bias is difficult to avoid, even when participants are aware of it (Englich et al., 2006). Because of this, the PAD sets the boundary for negotiations and often has a stronger influence on the outcome of negotiations, subsequent counteroffers, and establishes what the licensee views as BAS (Kristensen and Gärling, 1997).

Similarly, licensee generated Draft Biological Assessmets can strongly inform FERC documents and influence operational outcomes. BAs are formulated as part of the application (or as optional additional information). FERC then, "*can either take the information and incorporate it into their environmental document, make any necessary modifications to the BA and issue it, or adopt it [without changes] and supplement it as necessary*" (FERC, 2001). FERC stipulates the need for any information and conclusions to be verified. However, the relicensing process often places the burden of information largely on licensees. Information gaps, erroneous information, and alternative objectives may not be addressed unless they are recognized by FERC, NOAA, or other project stakeholders. Validation is resource intensive and may be applied irregularly depending on the resources stakeholders have available.

It is important to note the limitations of citation analysis for assessing information use from relicensing documents. First, not all information in the process is not formally cited. Because of this, disproportionate emphasis may be placed on published documents to the exclusion of other informational sources such as written comments, emails, etc. Moreover, some important documents, such as FERC Scoping Documents contain no citations despite the wealth of information they contain and their conspicuous role in the process. Additionally, citation analysis does not account for in-person interactions and meetings which may yield substantial information and are highly valued in the relicensing process (Porter and Birdi, 2018). Our research did not specifically address these sources of information and opportunity exists to capture this information through additional stakeholder surveys and interviews. Inconsistent stakeholder collaboration between hydropower projects and relicensing decisions result in differing intensity of personal communication between stakeholders. This can have a significant influence on the decision-making process. Highly collaborative projects for example, are "*more likely to increase capacity for joint action and result in satisfying settlement agreements*" (Ulibarri, 2015). The assessment of the importance of these informational sources and interactions would be best addressed using case study methodology in future research (see Pudry, 2012 and Ulibarri, 2015). Nuances to consider include informal sharing across projects and collaborations between agencies that could influence what stakeholders perceive as BAS.

Our survey data captured responses from a diverse group of individuals with a variety of relicensing responsibilities and expertise. It is notable that tasks relating to relicensing were not the primary job function of most respondents. Given the complexity of FERC relicensing, this may result in commitment and resource conflicts within agencies. One respondent stated, "*I may be asked to assist with some responsibilities, but this is outside of my performance plan*." Another mentioned providing "*scientific advice/support*" and "*technical input*" outside of their normal duties. Although respondents were generally experienced in relicensing activities, this experience was intermittent. One respondent stated:

> *A lot of times the agencies are limited in their ability to provide all the information necessary and available to the licensee and FERC. From my experience this is not due to a lack of willingness or ability, but rather simply the lack of enough people to do it all.*

A common theme in both the citation analysis and stakeholder survey is the importance of peer-reviewed publications as indicators of BAS. Without prompting, over half of federal and state respondents specifically wrote that they considered peer-review as BAS. For example, respondents stated that, "*peer-reviewed and published is highly valued – preferred*" and that, "*peer-reviewed papers are the gold standard*." This was further supported by high rankings of the relevance, comprehensiveness, objectivity, transparency, and availability for peer-reviewed publications from both groups (Table 2.3 and Figure 2.3). This was anticipated considering that many common definitions of BAS implicitly recommend review by experts as critical for establishing consensus and checking validity (e.g. ESA and NS2).

The reported use of informational sources mirrored the BAS value that respondents placed on them (Figure 2.3). Respondents used sources they deemed representative of BAS more frequently than others. This may influence information used in the relicensing process. As perceptions of BAS evolve among stakeholders, the types of utilized information may as well. This is a potential source of incongruence and conflict between stakeholders. The BAS rank of sources, and therefore their use, may diverge or even contradict each other requiring time and resource intensive arbitration by FERC.

Although ranked highly consistently, federal survey respondents valued and used peer-reviewed and academic sources more than state respondents (Figure 2.3). Conversely, state respondents valued and used expert opinion to a higher degree than federal employees. Differences in information access among agencies may be causal. Many peer-reviewed articles require payment for access, putting stakeholders with fewer resources at a disadvantage. While there was no difference shown in how federal and state respondents ranked the availability of peer-reviewed sources, several individuals described access as an impediment. One respondent stated, "*I am unable to access some peer-reviewed literature, and I actually have problems accessing data from other regions within my own Division*." Another stated a need for "*greater access to peer-reviewed literature and an easily searchable database of studies (and results) performed at FERC projects nationwide*." Perceptions of BAS and the use of sources was likely also driven by the geographic scope in which federal and state agencies work. Given the local nature and state-based responsibility of state resource agencies, respondents tended to report using personal information such as expert opinion. In comparison, federal respondents, with a larger regulatory scope, tended to use more traditional academic sources (Table 2.3).

For the most part, there was a similar degree of consensus among respondents irrespective of organizational affiliation (Figure 2.3). Perceptions of BAS for informational sources did not differ between federal and state agencies. There was relatively low consensus among federal and state respondent groups (e.g., relatively high PCI_2 values), especially for agencies governed by institutional and statutory guidelines promoting BAS (Figure 2.3). The lack of clear agreement on what BAS means likely makes it difficult to apply within a regulatory framework. Whether this is unique to our study area, or hydropower decision-making in general, is unknown and opens opportunities to study perceptions of BAS in other systems.

Though the majority of respondents felt that FERC receives adequate information to make informed decisions, some identified knowledge gaps including those related to basin-scale and cumulative impacts. One respondent stated that, "*cumulative effects are not adequately captured by the current science*," while another stated that, "*most watershed(s) lack comprehensive fisheries management plans needed for FERC to make informed decision that protect fisheries*." While licensees are required to address cumulative impacts at hydropower projects, FERC has not been required to use a pre-project environmental baseline to review project impacts. A respondent summarized this by saying, "*FERC largely looks at relicensing in the context of single project effects. For example, fish passage should be evaluated in the context of the larger fisheries picture in a watershed, such as ongoing and planned restoration*." Recently, however, the US Court of Appeals for the DC Circuit ruled that the "*failure to consider the damage already wrought by the construction of dams along the river fail[s] to meet the requirements under the ESA or NEPA*" (American Rivers v. FERC, 2018). Ensuing relicensing will likely be required to incorporate a pre-dammed environmental baseline as a consequence of this new litigation.

At the project-scale level, respondents stated their desire for "*real-time data*" and "*monitoring data*" including fish passage facility inventories, timing and rates of fish movement, raw fish counts, and streamflow data. "*For many smaller hydro projects, basic research on project specific impacts is not available and can be costly*," one respondent said. Another stated that:

> *…stream gages have been discontinued and many rivers in Maine are not gaged. This includes other data that is sometimes measured at stream gages such as temperature and turbidity. Also,*

> *a lot of information about hydropower dams such as project drawings and dam safety and inspection reports are marked as "privileged" and are therefore unavailable through the FERC eLibrary.*

Similarly, information such as fish counts are not obligatory, "*on the Androscoggin (Pejepscot and Worumbo) and in places on the Penobscot (West Enfield) there are fish passage systems but fish counts are not conducted (like at Milford). These are necessary*."

Finally, respondents stated the desire for a central repository for information (e.g., "*I would like to have information that may be difficult to get in a single archive*"). The FERC eLibrary partially fills this need for stakeholder correspondences, official relicensing documents, comments, and FERC orders. However, it can be difficult to navigate due to its rudimentary search capabilities and user interface. Survey respondents desired the inclusion of additional "*information (reports, literature, testimonials, etc.) available for each decision-making process*" and the ability to access "*old documents or information that has not been generated (e.g., new studies or as yet evaluated concepts)*." In particular, "*a better synthesis of similar study designs/methods/analytics for similar questions that are common*" was desired.

Given the politicization, interpretation challenges, and the competing demands inherent to relicensing, it is likely that the idea of BAS will continue to be a source of conflict among stakeholders. While information use in relicensing is inconsistent among stakeholders and individual perceptions of BAS are varied, our data suggest opportunities for improvement. Efforts to standardize BAS metrics within the relicensing process may benefit all participants, increasing transparency. Additionally, developing a shared information repository for documents such as studies, reports, and raw data may increase stakeholder access and use of BAS. Because the regulatory burden on federal and state agencies is anticipated to increase in the next two decades such changes may be advantageous.

CHAPTER 3

DEVELOPMENT OF A NOVEL BUOYANCY CONVERSION TAG FOR RECAPTURING FISH

Introduction

Historically, Alewife (*Alosa pseudoharengus)* and Blueback Herring *(Alosa aestivalis)* (collectively, river herring) sustained lucrative fisheries in the State of Maine and contributed important food, forage, and cultural resources to local communities (Nedeau, 2003; McClenachan et al., 2015). However, these fisheries have significantly declined in the last several decades due in large part, to the construction and maintenance of dams and the subsequent fragmentation of riverine habitat (Hall et al., 2011). As such, river herring conservation has become a high priority for fishery managers, conservationists, Tribal Governments, and local communities. Successful passage through dams, without injury, is critical for individual survival and population recovery. Numerous studies have assessed passage success for upstream migrating adults (See Bunt et al., 2011), representing one important component of their in-river life stage. Assessing downstream passage for out-migrating juveniles, however, presents unique challenges and is less informed (Silva et al., 2018). Therefore, the ability to assess downstream migratory passage is key for meeting management goals.

Downstream passage through hydropower facilities is achieved through three primary routes: turbine intakes, spillways, and fish bypass systems. Each can cause reductions in fitness (e.g., mortality, injury, and delay) through immediate and delayed means. These may include rapid pressure changes, cavitation, turbine strikes, shear stress, barotrauma, turbulence, and the compounded effects of multiple dams (FWS region 5, 2019). Passage facilities invariably differ among hydropower projects, creating the need to assess effectiveness for a range of passage structures.

One requirement for assessing successful passage rests in the ability of researchers to compare pre and post-passage fish condition. Generally, this requires the release of fish upstream, passage through the barrier, and recapture of the fish downstream. Tracking techniques such as radio and acoustic telemetry may be used to assess survival but offer little information on fish injury. Current techniques for physically recapturing fish to assess injury are available but limited. Weirs and nets positioned directly downstream of dams have been used to recapture fish, however, these can be difficult to apply in larger rivers and require a substantial investment of time, equipment, and personnel. Additionally, uncertainty in attributing injury causation can be exacerbated when dealing with the potential for injuries due to both the passage and recovery method.

In the absence of weirs, electronic sensor fish have been used to determine conditions faced by fish during passage (Deng et al., 2007b, 2014), however, these often carry a high price tag and force measurements may be difficult to relate to genuine fish injury. Other retrieval methods have been developed to detect and recover fish downstream. One solution is the HI-Z Turb'N Tag®, developed by Normandeau Associates Environmental Consultants (datasheet, 2012). These inflatable tags attach to fish prior to passage and, once activated, bring the fish to the surface where they can be recovered (Ferguson et al., 2004; Normandeau Associates, 2001). While effective, they are proprietary technology requiring costly third-party consultation agreements and may not be appropriate for small-bodied fish such as juvenile river herring. Low-tech methods have been used, such as attaching floatation foam to fish via a tether. Unfortunately, this can hinder the ability of fish to swim naturally and offers a mechanism for becoming entrained in debris.

The goal of this paper is to describe the development of a novel buoyancy conversion (BC) tag that may be used to facilitate fish recapture for passage assessments. The BC tag uses low-cost materials, does not significantly hinder fish movement, and has a delayed deployment. We provide a detailed description of the BC tag and describe the process used to optimize the tag for a range of fish sizes, specifically for juvenile river herring (32-152 mm). This work is intended for the public domain and is meant to be highly adaptable for use with many fish species and life stages.

Methods

Tag Optimization

Early work tested a novel buoyancy conversion (BC) tag. Work on this tagging approach was promising; the tags deployed as hoped and in a stream setting fish were easily recaptured. However, the pilot deployment ceased after the first field trials because of the challenge in recapturing the juvenile fish in the Penobscot River, Maine. In deeper water, river herring were able to keep the float submerged for a sustained period of time and evade those in a boat attempting to recapture the fish.

Phase II, reported here, was invested in optimizing the current tag design to counteract the pulling force that fish exert. In order to calibrate the weight and size specifications for the tag necessary for fish retrieval, we measured the downward swimming force for a range of fish sizes that would be comparable to the variance found in wild river herring populations. Due to the restricted availability of juvenile river herring, shiners (n=77) were used as a proxy ("Shiners" included common shiner (*Luxilus cornutus*) and emerald shiner (*Erimyzon oblongus)*). While behavioral traits and restrictions on wild release excluded shiners from being used in field trials, they functioned appropriately as a morphological and behavioral analog in laboratory testing. Shiners were purchased from a local provider and were known to be wild-caught. The use of commercially available fish allowed us to select for, and assess, a range of sizes. Because of injuries incurred during the lab experiments and the non-native/captive nature of commercially purchased fish, all subjects were euthanized upon completion.

Laboratory testing included placing each fish in a 110-liter tank. They were tethered to an anchored Trobal FB10 Force Gauge (Scientific Industries Inc. 80 Orville Dr. Bohemia, NY 11716) by a hook placed through the musculature caudal to the dorsal fin and a length of fishing line. Fish were allowed to swim for 40 seconds, during which time researchers encouraged a flight response from the fish causing them to swim in a consistent direction. Force measurements for all trials were recorded at 0.05-second intervals (n = 800 measurements per fish) and compiled. A force curve was generated as a function of mass (g) versus the maximum swimming force (N) that was achieved. Measurements were used to determine the buoyant force necessary to overcome the maximum swimming force allowing for the calibration of the weight and size specifications for the BC tag. The 0.90 quantile was chosen to functionally represent the upper bounds required for tag sizing relative to fish size.

Results

Sampled fish ranged in weight from 1.5 to 25.8 grams and length from 56 to 121 mm (Figure 3.1). All fish displayed instances of inactivity where the minimum force equaled zero. The maximum force ranged from 0.010 to 1.981 Newtons of force. Fish under five grams were generally unable to swim continuously while anchored. They did not exhibit a strong pulling ability and ceased swimming before the end of the trials. The weight of the hook used itself, prevented movement in these fish. Fish larger than five grams were able to swim more consistently and exhibited short bursts of flight at irregular intervals. The 90th quantile was derived from the maximum force measurements (Figure 3.2). It’s important to note that we used simplified calculations to measure buoyancy and swimming force. These calculations did not account for variables such as drag, water flow, and changes in water density. However, we argue that the calculations used provide a reasonable approximation of actual conditions. As a rule, tags should be scaled up to account for this variation and further testing is encouraged.

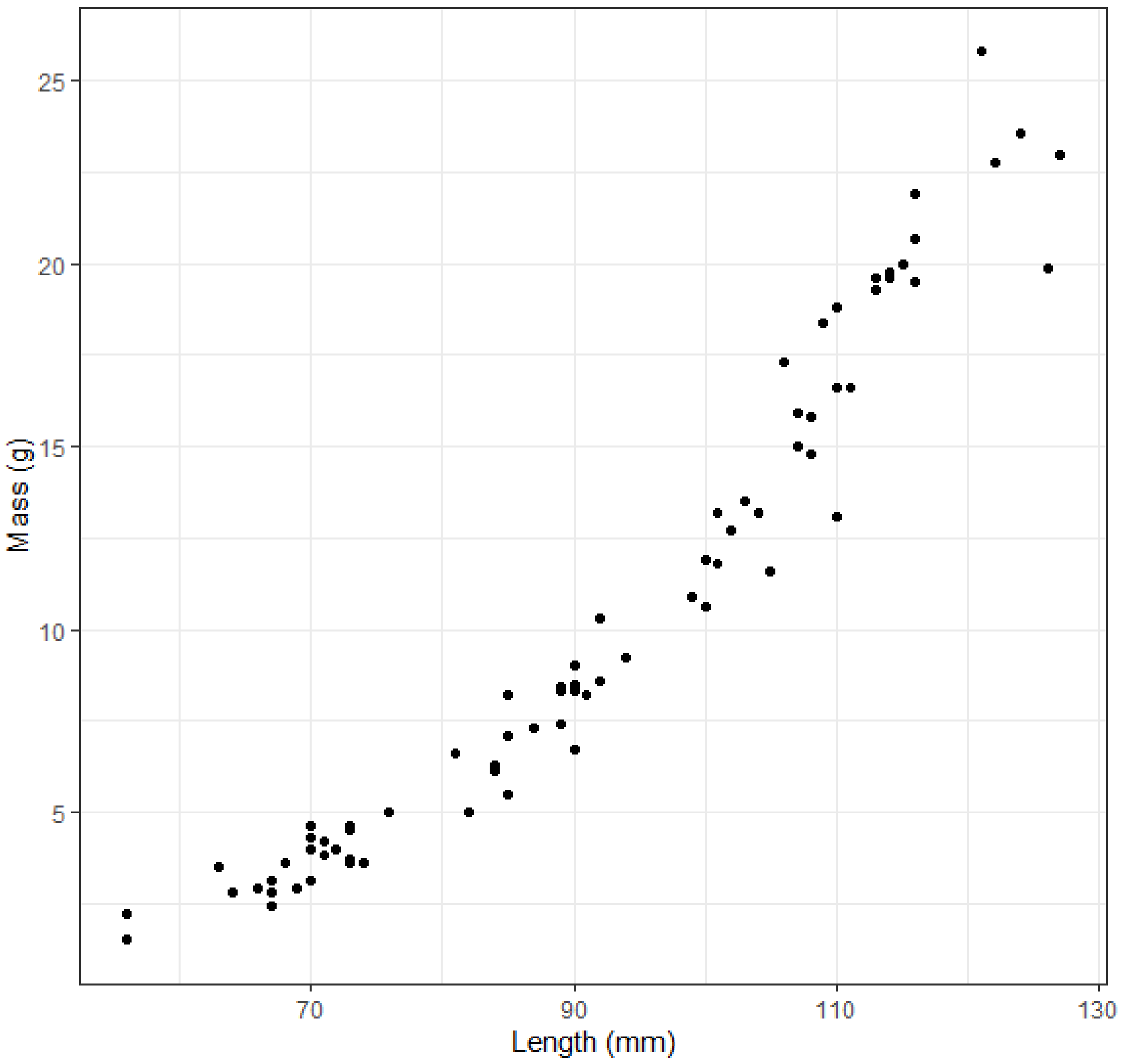


Figure 3.1. Size measurements. Mass (g) and length (mm) of 77 sampled fish.

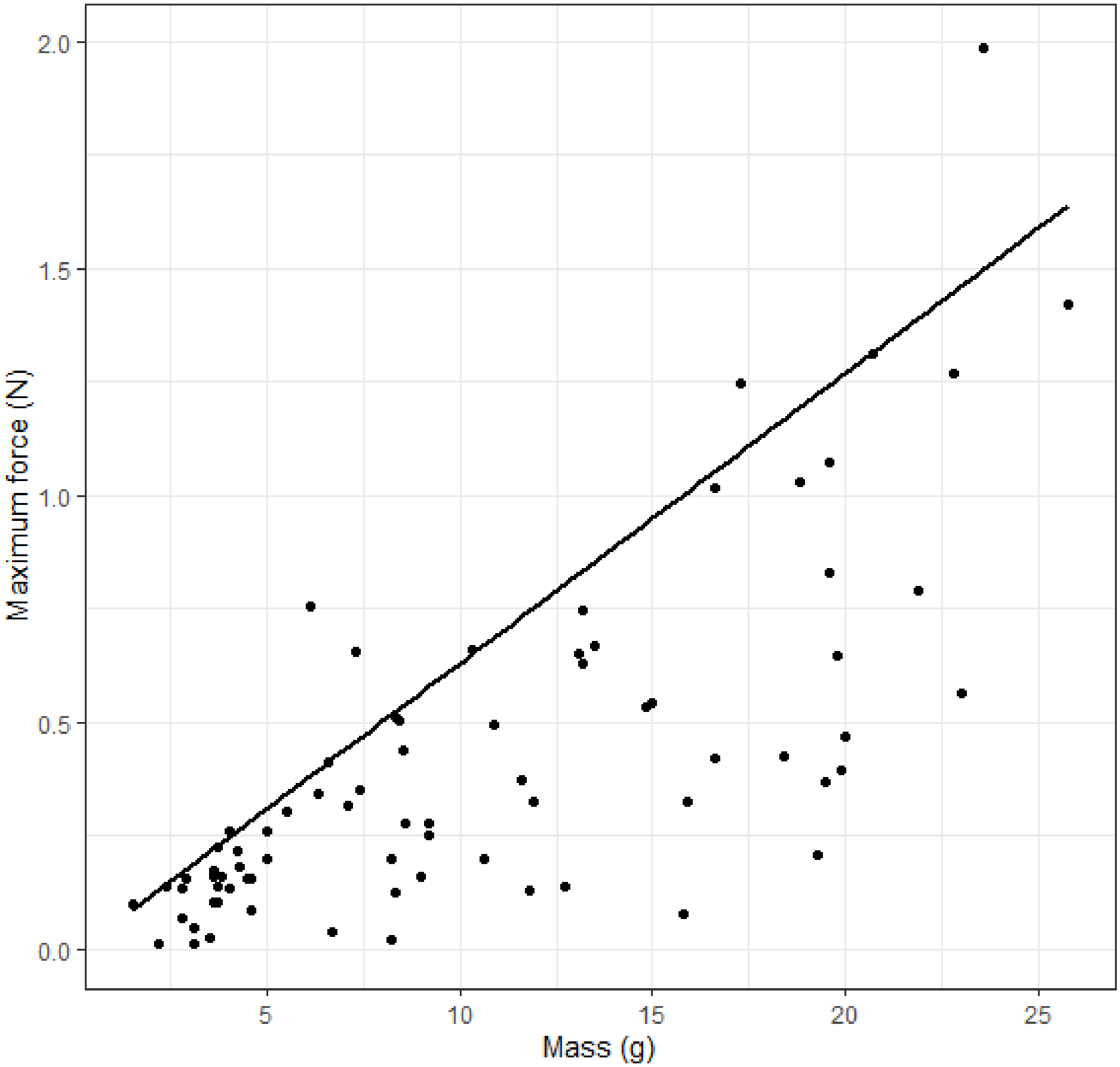
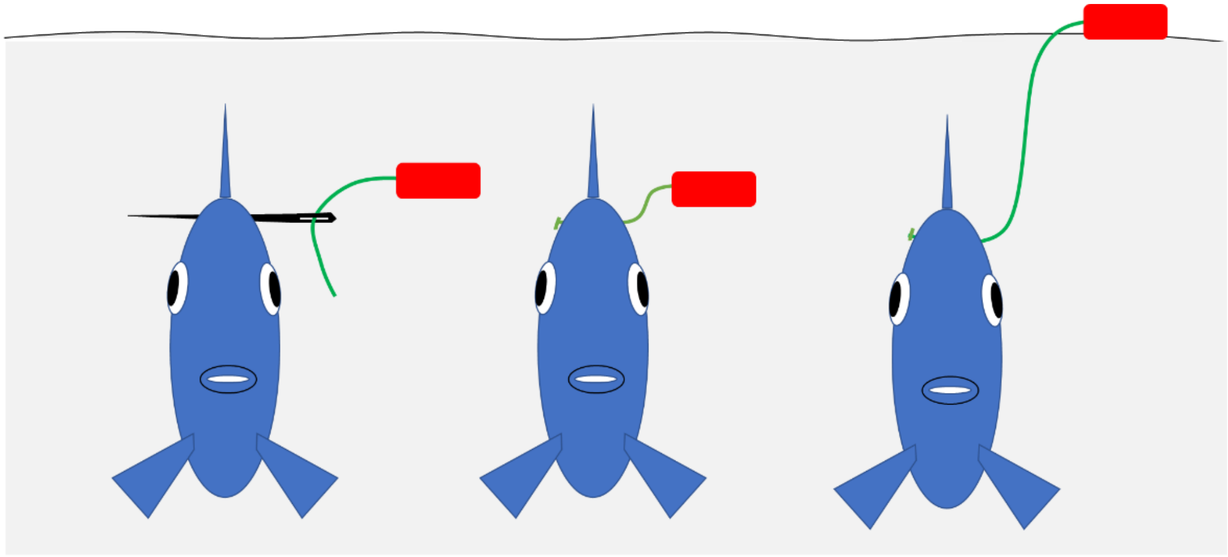


Figure 3.3. Maximum force measurements. Maximum force achieved by fish during 40 second pulling trials as measured by a digital force gauge. The relative strength that fish exhibit increases with size. The 0.90 quantile was chosen to functionally represent the upper bounds required for tag sizing relative to fish size.

Buoyancy Conversion Tag Description

The inactivated floatation device is fastened to the fish by means of a tether, consisting of nylon monofilament, typically fishing line (Figure 3.3). The tether is attached to a hook which is inserted through the musculature of the fish, preferably below the posterior edge of the dorsal fin. Other methods of attachment may be applied, such as the use of a piercing gun or needle. The floatation device at the opposite end of the tether is constructed of a non-proteinaceous Hydroxypropyl Methyl Cellulose capsule which is water soluble. Collagen derived, typically gelatin, capsules may be used in warm water, however they exhibit restricted solubility in water below 30 °C. Inside the capsule is a segment of foam (21 x 10 mm), preferably a cylinder matched to the diameter of the capsule. The foam is attached to the tether by a needle passed through and tied off. It is recommended that the remaining length of the tether is coiled independent from the foam and placed freely in the capsule. Coiling the tether around the foam results in snags and may inhibit deployment. Weights, typically non-toxic metal shot, are added to the capsule to counteract the buoyancy of the foam, keeping it neutral in the water column.

The key benefit of the BC tag is its capacity for delayed deployment until after passage through an obstacle. It may be desirable to increase or decrease the rate at which the capsule dissolves. Factors that affect the dissolution rate include capsule material, capsule thickness, and water temperature. During our trials, tags reliably deployed within five minutes. Initially the tag is neutrally buoyant and trails behind the fish. The tag is small and moves freely, thus, does not impede normal swimming behavior. Upon dissolution of the capsule, the foam is released to float to the surface providing a visual indicator of fish location, facilitating fish retrieval. Because the fish remains below water, trauma to the fish using this method is minimized. Best results can be obtained if the BC tag is sized to the swimming strength of the fish based on general length measurements. The size of individual components (e.g. capsules, foam, tethers, weights, and hooks) may be customized to suit research needs.



a. Attachment of tag using a monofilament line

b. Deployment of tag, initially neutrally buoyant.

c. After 5-8 minutes, the time released tag floats so that it is visible to researchers

Figure 3.3. Buoyancy conversion tag deployment. Indicators are meant to (*a*) attach through the musculature of fish using a standard lead-free hook with monofilament line, (*b*) remain neutrally buoyant during obstacle passage, and (*c*) deploy after 5 minutes for recapture by researchers. In cold water, tags must be made from cellulose capsules in order for the release of the foam to occur.

Table 3.1. Buoyancy conversion tag specifications. Optimal conditions for use of BC tags for the retrieval of fish in the field.

	Gelatin capsules	**Hydroxypropyl methylcellulose (HPMC) capsules**	**Polyvinyl alcohol (PVA) fishing aids (capsules, bags, and mesh)**
Size range	-regular: 5-000 -extended: 13-110 ml	-regular: 5-000	-variable
Pros	-widely available -inexpensive -available in large sizes	-widely available -inexpensive -dissolves in cold water	-dissolves in cold water -available in multiple forms
Cons	-does not dissolve well in cold water	-does not come in sizes greater than '000'	-dissolves quickly -some forms may be expensive and difficult to find
Ideal Application	-warm water scenarios (>50C)	-cold water scenarios (<50C) *due to size restrictions multiple tags may need to be affixed to the fish	-scenarios with site-specific requirements

Additional materials and conditions:

- Attachment: fish hook or needle
  - Sized appropriately to fish size
  - As lightweight as possible
- Tether: fishing line
  - Sized appropriately to fish strength
  - As lightweight as possible
- Floatation: foam cylinders, bobbers, strike indicators, etc.
  - Floatation material may be sized to fit inside of the capsules
  - Alternatively, it may be constructed to float freely, but attached to the weighted capsule
- Weight: BBs, sand, buck shot, etc.
  - Preferably lead free
  - Must negate the buoyancy of the floatation material used

Future Development

The Penobscot River Restoration Project (PRRP) facilitated the removal of two dams and other passage improvements aimed at restoring sea-run fish to the Penobscot River. Among its outcomes, the PRRP led to the installation of a nature-like fish bypass at the Howland Dam in Howland, Maine. This type of dam infrastructure is generally seen as the gold standard in fish passage for reducing mortality and injury, however, this has not been confirmed at the Howland Bypass. Downstream passage for fish may be through either the nature-like bypass or a concrete sluiceway that includes a 1.5-meter drop. The BC tag will be used to assess fish injury through both structures. This will further contribute to our overall understanding of fish passage in the Penobscot River and provide a guide for those engaging in similar passage assessments. This proof of concept will be demonstrated through field trial.

A maximum of 300 river herring, will be captured using dip-netting from the Saudapscook River in Maine. Because of their similar morphology and life history, both species will be used, however, alewife are expected to be taken more frequently due to being more common in Maine rivers. River herring will be transported to the Howland Bypass for field tests which include three release treatments (e.g., T1 = nature-like bypass; T2 = concrete sluiceway; T3 = control). Fish in T1 and T2 will be released into the beginning of the bypass/sluiceway while T3 will be released directly into the Howland tailrace, thereby avoiding all dam infrastructure. Fish will be released with minimal disturbance and handling. All fish will be recovered in the tailrace after BC tag deployment.

Groups of 10 fish will be processed at a time, rotating through each treatment type until gone. Prior to release, the BC tags will be affixed to the fish at an attachment point through the musculature medial to the dorsal fin. Each fish and corresponding tag will be kept in an individual container to avoid tag entanglement and allow the tags to begin softening. Fish will be released directly into the water, where directional flow is expected to encourage movement downstream. If possible, fish may be visually tracked through their downstream movement. Once the tag is deployed, this float will encourage fish to swim near the water surface for recapture. In the tailrace, researchers will be situated onshore and in canoes to sight and capture the deployed tags. In order to prevent the possibility of scale loss and damage associated with confinement post-trial, all subjects will be euthanized upon recapture using approved AVMA procedures. Physical assessments will be taken post-mortem to assess any injury incurred during downstream passage. Comparison of passage type will be done using one-way ANOVA followed by a Tukey's post hoc test. Data transformations will be conducted as needed to meet the assumptions of normality and homogeneity of variance. Significance will be assessed at 0.05.

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APPENDIX A: SUMMARY OF SELECT HYDROPOWER RELICENSING DOCUMENTS

Table A.1. Relicensing document summary. Summary of the documents required during the hydropower relicensing process including author information, legal trigger, and timing under the FERC Integrated Licensing Process followed by a brief narrative of the process.

Documents	Author	Trigger	Timing under ILP	Description
Pre-application Documents (PAD) (n=5)	Licensee	FPA licensing requirement	Start of licensing process (5-5.5 years prior to license expiration)	Contains existing information relative to the project proposal found through due diligence
Biological & Habitat Assessments (n=7)	Licensee (often adopted by FERC into EIS/EA)	Optional	Concurrently with scoping	Optional assessment of environmental impacts, fish habitat, and species protection plans. Results are often checked by resource agencies and FERC and are incorporated into the EA/EIS
Study Plans & Reports (SP&R) (n=15)	Licensee	FPA licensing requirement	45 days from PAD comment deadline	Scheduled plans of action and subsequent reports for studies to be carried out prior to the license application
Biological Opinions (BiOp) (n=8)	NOAA/ USFWS	ESA, Sec 7 consultation if endangered species are present	135 days from initiation of formal consultation	Formal consultation required when a project is “likely to adversely affect” ESA listed species. Due to the focus on diadromous fish conservation in our study area, NOAA Fisheries was the primary author
License Applications (n=11)	Licensee	FPA licensing requirement	2 years prior to license expiration	The culmination of previous studies, consultation efforts, and planning addressed in a final application document
Environmental Assessments (EA) OR Environmental Impact Statements (EIS) (n=16)	FERC	NEPA licensing requirement	Following license application, within 180 days from the end of the comment period	Addresses the effects of a project on the human environment (EIS used if the project may have a “significant effect”)

The first relevant document in the relicensing process is a **Notice of Intent** to Seek Relicensing (NOI) and a **Pre-Application Document** (PAD) filed by the licensee at least five, but no more than five and one half, years before the expiration of the current license (18 CFR § 5.5(d)). The PAD proceeds the environmental analysis of the preliminary license application and the two documents often mirror each other. The PAD provides existing information relevant to the project in order to identify potential issues early. It acts as a platform for stakeholders to develop information requests, study requests, study plans, and to prepare additional documents. Licensees are not required to conduct studies at this stage but must exercise due diligence in organizing information and describing the existing environmental and potential impacts of the project. Sources of information included in the descriptions and summaries must be referenced in the document and made available upon request.

Within 60 days of the NOI and PAD, FERC is required to provide a **Scoping Document** and Notice of Commencement (18 CFR § 5.8(c)). These documents 1) summarize the procedures of the licensing process, including formal means of participation, 2) describe the project, proposed protection and enhancement measures, and possible alternatives, and 3) identify resource issues to be analyzed, including the consideration of cumulative impacts. The Scoping Document also provides a schedule of the licensing process and incorporates the coordination of federal, state, and tribal permitting process. Comments on the PAD and Scoping Document and study requests are encouraged within 60 days of the Notice of Commencement (18 CFR § 5.9(a)). A second Scoping Document may be issued if deemed necessary (18 CFR § 5.10).

In the ILP, pre-filing consultation is conducted concurrently with NEPA scoping. The filing of the NOI and PAD initiate both FERC scoping and mandatory consultation efforts. Endangered Species Act (ESA) Section 7 consultations and **Fish Habitat assessments** are such requirements. ESA consultations determine if a project will adversely affect a threatened or endangered species, allowing USFWS and NOAA to establish reasonable and prudent alternatives (RPA) or measures (RPM) (ESA Section 7(a)(2)). ESA consultation may remain informal unless the project is found to adversely affect the listed species or its designated critical habitat (50 CFR 402.02 and 402.13). A **Biological Assessment**, prepared by FERC, determines potential effects, resulting in an assessment of “no effect,” “may effect, but is not likely to adversely affect,” or “may affect, and is likely to adversely affect.” Though FERC is ultimately responsible for this determination, the licensee may optionally prepare their own biological assessments and fish habitat assessments. These are often integrated into FERC's Biological Assessments and concurrent Environmental Assessments/Environmental Impact Statements.

If a determination of "may affect, and is likely to adversely affect," an endangered species is made, USFWS or NOAA prepares an incidental take statement and a **Biological Opinion (BiOp)**. The BiOp includes a description of the proposed action, the status of the endangered species and its critical habitat, environmental baselines, cumulative effects of the proposed action, the agencies conclusion of jeopardy or no jeopardy, and reasonable and prudent alternatives. The BiOp must be delivered within 135 days of the initiation of formal consultation.

A **Study Plan** is submitted by the licensee within 45 days from the PAD comment deadline. It includes detailed descriptions of the proposed studies, schedules for completion, provisions for progress reports, and explanations for rejecting requested studies (18 CRF § 5.11(a)). It must describe study goals and objectives, address known resource management goals, describe existing information concerning the study system, explain direct, indirect, and cumulative operational effects, support proposed methodology, and describe considerations for cost and effort (18 CRF § 5.11(b)). Comments are encouraged for 90 days following the issuance of the proposed Study Plan (18 CFR § 5.12) and requests for additional studies must be accompanied by substantial reasoning. A revised Study Plan is issued by the licensee in response to comments within 30 days of the commenting deadline (18 CFR § 5.13(a)) and FERC makes a determination. Study disputes may only be made by agencies with the authority to provide mandatory license conditions under section 4(e) and 18 of the Federal Power Act or section 401 of the Clean Water Act (18 CFR § 5.14(a)) and are subject to panel review.

Study Reports follow the implementation of the final study plan (18 CFR § 5.15(a)). Study progress, data collection, explanation of variance, and proposed new studies must be reported no later than 1 year after FERC approval of the study plan (18 CFR § 5.15(c)). A study meeting must be held with agencies and FERC staff within 15 days of the initial study report with a meeting summary produced by the licensee within 15 days of the meeting. Participants of the meeting can file disagreements about the meeting summary within 30 days which FERC resolves. If no disagreements are raised, the contents of the report are deemed approved. New studies may be requested at any time with an explanation of why the request as not made earlier and why the new study is necessary (18 CFR 5.15(d)). FERC determines if a new study should be conducted.

The licensee must submit a preliminary **License Application** proposal 2 years prior to the expiration of the current license (18 CFR 5.16(a)). Applications describe the existing and proposed project facilities, describe existing and proposed operation and maintenance plan, and include the licensee's draft environmental analysis with study results. They are required to include measures and plans to protect, mitigate, or enhance environmental resources. Stakeholders may comment on the license application within 90 days of its filing (18 CFR 5.16(e)), including recommendations on whether an Environmental Assessment or Environmental Impact Statement should be constructed by FERC. The final license application must address ESA consultation, MSA consultation, and CWA water quality certification. Additionally, it must address the Coastal Zone Management Act, National Historic Preservation Act, and Wild and Scenic Rivers and Wilderness Acts authorities.

Once a license application is accepted, FERC issues a Notice of Acceptance and Readiness for Environmental Analysis at which time comments are invited within 60 days (18 CFR 5.23(a)). Mandatory terms and conditions, prescribed by applicable agencies must also be filed within 60 days. These include Forest Service conditions (16 USC 796(2)), Comprehensive Plan conditions (FPA Section 10(a), preliminary fish and wildlife recommendations by USFWS and NOAA (FPA Section 10(j)), mandatory fishway prescriptions by the Secretaries of Commerce and the Interior (FPA Section 18), and Agency Conditions and Recommendations provided by other agencies. Taking these recommendations and comments into consideration, a draft **Environmental Assessment (EA) or Environmental Impact Statement (EIS)** is prepared by FERC pursuant to the National Environmental Policy Act (NEPA). It must include draft license articles, determinations in regards to agency recommendations, and preliminary terms and conditions and fishway prescriptions. Participating agencies may amend recommendations (18 CFR 5.25(d)) and a final EA issued.

APPENDIX B: FREQUENTLY USED SOURCES OF INFORMATION IN HYDROPOWER RELICENSEING

Table B.1. Frequently Used Informational Sources. The most frequently used sources of information as cited in hydropower relicensing documents used to study best available science. In general, the most frequently cited documents were resource conservation plans and dealt primarily with Atlantic salmon.

Title	Author, date	Number of times cited	Percent of total citations
Endangered and Threatened Species. Designation of critical habitat for Atlantic salmon (*Salmo salar*) Gulf of Maine Distinct Population Segment. Final rule.	NMFS, 2009	22	0.4%
Status review for anadromous Atlantic salmon (*Salmo salar*) in the United States.	USFWS, 2006	20	0.4%
Final Recovery Plan for the Gulf of Maine Distinct Population Segment of Atlantic Salmon	NMFS & USFWS, 2005	18	0.4%
Kennebec River Resource Management Plan: Balancing Hydropower Generation and Other Uses	ME State Planning Office, 1993	17	0.3%
Atlantic Salmon Spawning Migrations in the Penobscot River, Maine: Fishways, Flows and High Temperatures	University Thesis, 1995	16	0.3%
Operational Plan for the Restoration of Diadromous Fishes to the Penobscot River	MDMR & MIFW, 2009	15	0.3%
Atlantic salmon. Pages 192-197 in Freshwater Fishes of Canada (Bulletin 184)	Dept of Fisheries and Oceans, 1973	15	0.3%

APPENDIX C: USE OF SCIENTIFIC KNOWLEDGE IN HYDROPOWER RELICENSING QUESTIONNAIRE

Use of Scientific Knowledge in Hydropower Relicensing

Developed by:
Sarah K. Vogel
Dr. Joseph Zydlewski
Dr. Jessica S. Jansujwicz

STRENGTHENING THE SCIENTIFIC BASIS FOR DECISION MAKING ABOUT DAMS

CONSENT FORM FOR RESEARCH

You have been asked to participate in a research project described below. The researcher will explain the project to you in detail. You should feel free to ask questions. If you have more questions later, Dr. Todd Guilfoos (401) 874-4398, the person mainly responsible for this study, will discuss them with you. You must be at least 18 years old to participate in this research project.

Description of the project:
This study examines decision making preferences and processes about dams. We hope to learn about public preferences for ecosystem services from dams, common arguments for and against dams, and how collaborative decision processes impact decisions about dam removal, rehabilitation, and upgrading.

What will be done:
You have been invited to participate in the following research components (*check one or more*):

___ In the **interview and/or stakeholder survey** portion of this study, you will be asked a series of questions about dams, decision making, and collaboration. Interviews are expected to last from 30 to 120 minutes, while surveys will take approximately 20 minutes to complete. Interview participants may be asked for follow-up interviews.

___ In the **lab experiment**, you will be presented with a sequence of decisions that provide you an opportunity to make money. Your earnings will be affected by your decisions and the decisions of others. The process should take not more than two hours.

___ In the **choice experiment**, you will be asked to complete either an internet-based survey or an in-person workshop. Survey participants will answer a series of questions about valuing ecosystem services related to dams. Workshop participants will be asked to complete complex decision making tasks related to valuation. Surveys will take approximately 20 minues, while workshops will take not more than two hours.

___ In the **role-play simulation/charrette**, you will be asked to provide feedback about several computer models and take on the role of a particular type of stakeholder to work through the tradeoffs related to particular dam decisions. These two workshops are expected to last approximately 6 hours each.

Risks or discomfort:
It is unlikely that you will incur any risks or will experience any discomfort as a result of participating in this study.

Benefits of this study:
Although there may be no direct benefit to you from participation in this study, the researchers may learn more about how people use science to make decisions about dams and about how collaboration impacts decision making, resulting in better decision making about dams.

Confidentiality:
Your part in this study is confidential. None of the information will identify you by name. Your name will not be included in the transcript of interviews, role-plays, or charrettes. Audio recordings will be erased after they are transcribed. Signed consent forms will be kept in the investigator's locked cabinet, separate from any transcripts. For the experiments, decisions will be linked by a subject number assigned to you by the researcher. This subject number will never be linked to anything which can identify you. Other participants in the experiment will not be able to attribute your decisions to you personally, and they will not know how much you earn. At the end of the experiment, you will have to sign for the amount of your earnings. This form will not contain your subject number, and will not be linked with your decision data.

Decision to quit at any time:
The decision to take part in this study is up to you. You do not have to participate. If you decide to take part in the study, you may quit at any time. Whatever you decide will in no way penalize you. If you wish to quit, simply inform the researcher of your decision.

Rights and complaints:
If you are not satisfied with the way this study is performed, you may discuss your complaints with Dr. Guilfoos or with staff members at the office of the Vice President of Research and Economic Development (401-874-4328), anonymously, if you choose. In addition, if you have questions about your rights as a research participant, you may contact the office of the Vice President of Research and Economic Development, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, RI, telephone: 401-874-4328.

You have read this Consent Form. Your questions have been answered. Your signature on this form means that you understand the information and you agree to participate in this study.

______________________________ Signature of Participant	______________________________ Signature of Researcher
______________________________ Typed/printed Name	______________________________ Typed/printed name
____________________ Date	____________________ Date

Please sign both consent forms, keeping one for yourself

___ I agree to let the researcher **audio record** the interview. Audio recordings will be held until they are transcribed, at which point they will be destroyed. If you agree, please sign below:

________________________ Signature ________________ Date

Use of Scientific Knowledge in Hydropower Relicensing Survey

- *Q1-Q3) Consent to take the survey*

The following questions gauge your experience and role within the hydropower relicensing process.
All information collected will remain confidential.

- Q5-Q6) Which organization are you employed by?
- Q7) What is your current job title?
- Q8) How long have you held your current position?
- Q9) How many years of experience do you have working directly or indirectly with hydropower issues?
- Q10) Are you or your organization a formal participant in the FERC hydropower relicensing process?
- Q11) How frequently do you participate in the following relicensing responsibilities?

	Do not participate				Frequently participate
FERC document review	1	2	3	4	5
Provide official written comments	1	2	3	4	5
Scoping meeting participation	1	2	3	4	5
Coordination with other entities	1	2	3	4	5
Study design planning	1	2	3	4	5
Scientific evaluation and synthesis	1	2	3	4	5
Task force/committee participation	1	2	3	4	5
Supervisory role	1	2	3	4	5

- Q12) Please use this space to identify relicensing responsibilities you participate in that weren't addressed.
- Q13) How frequently do you employ the following expertise/skills in your work

	Do not employ				Freq. employ
Fisheries	1	2	3	4	5
Engineering/fish passage	1	2	3	4	5
Hydrological	1	2	3	4	5
Policy (e.g., ESA authorities)	1	2	3	4	5
Communication	1	2	3	4	5
Negotiation/mediation	1	2	3	4	5
Community engagement	1	2	3	4	5

- Q14) Please use this space to identify expertise/skills you employ that weren’t addressed above.
- Q15) In your opinion, what constitutes “best available science?”
- Q16) In your opinion, how relevant is the information provided by the following sources to your work? (i.e., How appropriate to the current time period and circumstances is the information?)

	Not relevant				Extremely relevant
Unpublished academic research (e.g., theses)	1	2	3	4	5
Agency grey literature	1	2	3	4	5
Industry reports	1	2	3	4	5
Community comments	1	2	3	4	5
Peer-reviewed publications	1	2	3	4	5
Expert opinion	1	2	3	4	5

- Q17) In your opinion, how comprehensive is the information provided by the following sources? (i.e., How complete and inclusive is the information?)

	Not comprehensive				Extremely comprehensive
Unpublished academic research (e.g., theses)	1	2	3	4	5
Agency grey literature	1	2	3	4	5
Industry reports	1	2	3	4	5
Community comments	1	2	3	4	5
Peer-reviewed publications	1	2	3	4	5
Expert opinion	1	2	3	4	5

- Q18) In your opinion, how objective is the information provided by the following sources? (i.e., How impartial and unbiased is the information?)

	Not objective				Extremely objective
Unpublished academic research (e.g., theses)	1	2	3	4	5
Agency grey literature	1	2	3	4	5
Industry reports	1	2	3	4	5
Community comments	1	2	3	4	5
Peer-reviewed publications	1	2	3	4	5
Expert opinion	1	2	3	4	5

- Q19) In your opinion, how transparent is the information provided by the following sources? (i.e., Is the information clear and the approach to data collection understandable? Can information be validated/verified?)

	Not transparent				Extremely transparent
Unpublished academic research (e.g., theses)	1	2	3	4	5
Agency grey literature	1	2	3	4	5
Industry reports	1	2	3	4	5
Community comments	1	2	3	4	5
Peer-reviewed publications	1	2	3	4	5
Expert opinion	1	2	3	4	5

- Q20) In your opinion, how available is the information provided by the following sources? (i.e., How accessible and obtainable is the information?)

	Not available				Extremely available
Unpublished academic research (e.g., theses)	1	2	3	4	5
Agency grey literature	1	2	3	4	5
Industry reports	1	2	3	4	5
Community comments	1	2	3	4	5
Peer-reviewed publications	1	2	3	4	5
Expert opinion	1	2	3	4	5

- Q21) How frequently do you consult the following sources to obtain the data/information needed for your work?

	Do not use				Frequently use
Unpublished academic research (e.g., theses)	1	2	3	4	5
Agency grey literature	1	2	3	4	5
Industry reports	1	2	3	4	5
Community comments	1	2	3	4	5
Peer-reviewed publications	1	2	3	4	5
Expert opinion	1	2	3	4	5

- Q22) What do you consider the main strengths of the sources you use frequently?
- Q23) What type of information would be beneficial to have, but is currently unavailable to you?
- Q24) Please use this space to identify sources of information you use that weren't addressed above.
- Q25) How often are your recommendations taken into account by others?

	Never				Frequently
Within your organization	1	2	3	4	5
Outside your organization	1	2	3	4	5

- Q26) How much decision-making power do you believe the following organizations wield in the relicensing process?

	No Power				Extreme Power
NOAA	1	2	3	4	5
USFWS	1	2	3	4	5
Tribal Nations	1	2	3	4	5
FERC	1	2	3	4	5
MDMR	1	2	3	4	5
MDIFW	1	2	3	4	5
MDEP	1	2	3	4	5
Licensees	1	2	3	4	5
Conservation Organizations	1	2	3	4	5

- Q27) Please list any organizations that weren't mentioned above that you believe wield significant power in the process.
- Q28) Why do you believe your organization has the level of influence that it does?
- Q29) In your opinion, how influential are the following official comments on FERC's decision-making?

	Not at all influential				Extremely influential
Federal agency comments	1	2	3	4	5
Tribal Nation comments	1	2	3	4	5
Town/city comments	1	2	3	4	5
Citizen/public comments	1	2	3	4	5
State agency comments	1	2	3	4	5
Licensee comments	1	2	3	4	5

- Q30) Do you feel that FERC receives adequate information to make informed decisions about fish passage during hydropower relicensing?
    - Q31) What information do you believe is lacking in current decision making about fish passage?
- Q32) Can you recommend anyone else we should contact regarding these issues? Please include their contact information below. All information will remain anonymous.
- Q33) This concludes the Use of Scientific Knowledge in Hydropower Relicensing Survey. Thank you for taking the time to inform our research. We value your opinions and feedback. Please take a moment to write any additional comments you may have.

BIOGRAPHY OF THE AUTHOR

Sarah Vogel was born in Oconomowoc, Wisconsin on July 19, 1984. She was raised in Milwaukee, Wisconsin where she attended St. Joan Antida High School for three years. She moved to New York during her senior year and graduated from Sachem North High School in Lake Ronkonkoma, New York in 2002. She moved to Tennessee in 2004 where she worked for several years in a leadership role as an operations and human resources manager for a large retailer. She attended Tennessee Technological University as a non-traditional student in 2009 and graduated with two bachelor’s degrees (Wildlife and Fisheries Sciences and Environmental Biology) in 2012. She traveled and worked closely with bats and amphibians in Tennessee and Arizona before pursuing a graduate degree. In the spring of 2017, Sarah began a graduate research assistantship at the University of Maine in the Department of Wildlife, Fisheries, and Conservation Biology. Throughout her college career, she remained active in The Wildlife Society, the American Fisheries Society, and the American Institute of Fishery Research Biologists. After receiving her degree, Sarah will continue to work closely with dam relicensing projects. She aspires to work in state or federal government and may pursue a PhD to continue a career in wildlife and fisheries research. Sarah is a candidate for the Master of Science degree in Wildlife Ecology from the University of Maine in December 2019.