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Science in action or science inaction? Evaluating the implementation of "best available science" in hydropower relicensing

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ABSTRACT

Over the next two decades, half of all hydropower projects in the USA will require relicensing by the Federal Regulatory Commission (FERC). Relicensing proceedings invoke a range of informational sources and 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. The Kennebec and Penobscot River watersheds in Maine provide an ideal opportunity for studying BAS in the relicensing process in the context of fish passage concerns. Using citation analysis and an online survey, we identified informational sources used in relicensing decisions for dams in this system and assessed agency perceptions of BAS. Analysis of relicensing documents (n=62) demonstrates that FERC and licensee documents are highly similar in citation composition. National Oceanic and Atmospheric Administration (NOAA) documents typically cite more sources and are three times more likely to cite peer-reviewed sources than FERC and licensee documents. Survey data reveals that federal and state agency respondents (n=49) rate peer-reviewed literature highly as BAS, followed by university, agency, and expert sources while industry and community sources rate poorly. Federal respondents report using peer-reviewed/academic sources more frequently and expert sources less frequently than state respondents. Overall, the agreement between individuals with respect to the valuation of sources is low. The reported differences in information use may be linked to disparities in the access to certain sources of information, particularly peer-reviewed literature. Enhanced understanding of information use may aid in identifying pathways for better informed relicensing decisions.

1. Introduction

Hydropower dams are often considered a clean source of domestic renewable energy and important in lowering dependence on fossil fuels (Dincer and Acar, 2015). In the USA, hydropower is the fourth largest source of electricity generation, behind natural gas, coal, and nuclear. Dams can enhance recreational benefits for fishing and boating, provide impoundments for flood and fire control, and support water supply and irrigation needs (Poff et al., 1997). Moreover, dams may be culturally and historically significant to local communities (Graf, 2005). For these reasons, dams are likely to remain persistent structures on our landscape.

Nevertheless, dams change the ecology of rivers. They can reduce water quality and dissolved oxygen, increase sedimentation and water temperature, and change geomorphology (Poff et al., 2007; Graf, 2005). Additionally, they alter and fragment riverine habitat in ways that can be detrimental to diadromous fish, those with complex life cycles which require movement between salt and fresh water (Hall et al., 2011; Linnansaari et al., 2015). Notable declines in culturally and economically important species have led to more intense scrutiny of hydropower dam operations. 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 and have been identified as a leading cause for population declines (Limburg and Waldman, 2009).

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 USA 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. § 791

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[a]). FERC is governed by five Commissioners, appointed by the President, not to exceed a 3:2 ratio of either Democratic or Republican appointees. Licenses last 30 to 50-years and must be relicensed periodically providing a short window of opportunity for reassessing project operations. 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 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). Additionally, it is critical to the continued operation of hydropower generation.

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). While FERC remains the primary authority in this process, the current regulatory framework stipulates input from other stakeholders. Agencies, Tribal Governments, project licensees (e.g., the person/-organization to which the dam is licensed), and conservation organizations with different roles, responsibilities, and statutory obligations may provide input to the process. Federal and state resource agencies, in particular, have the ability to affect license conditions by invoking a suite of regulatory authorities (Richardson, 2000). 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). 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). Using the Kennebec and Penobscot Rivers in Maine as a model system, we sought to explore how information is used and valued by stakeholders in the FERC relicensing process. Specifically, we framed our study to address information use within the context of fish passage concerns, a predominant theme in many relicensing decisions. Though limited, this framing identifies and addresses trends in information use that may occur in any river with historic ocean connectivity and may be applicable beyond fish passage decision-making. 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.

1.1. 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 (NOAA) National Marine Fisheries Service 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 project 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(a)(2)). 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 (NRC) (National Academies Press, 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). Though it gives broad guidance on what constitutes BAS, it does not outline concrete metrics for applying the criteria. For example, the NS2 suggests that, *"methods used to produce the scientific information should be verified and validated to the extent possible,"* however, it does not provide a marker for what constitutes the *"extent possible"* or *"correct"* methods of validation. The NS2 specifically cautions 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, requiring a great deal of professional judgement. This research seeks to clarify the concept and inform more effective use of BAS in hydropower relicensing decisions.

1.2. 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. Both rivers were of high importance in the nineteenth century for the transport of timber and paper production, leading to the construction of dams for water control (Gibson, 2017). While river use has changed over time, hydropower dams still play an important part in Maine's economy, contributing 450 thousand megawatts of power (U.S. Energy Information Administration, 2019). In 2018, 25 percent of net electricity generation came from hydropower, the most per capita of any state East of the Mississippi (U.S. Energy Information Administration, 2019). Despite

this, most individual projects in the Kennebec and Penobscot Rivers do not have an authorized capacity of more than 20000 MW. Rather, the system has many, relatively small projects producing this energy. A 2015 investigation into expanding Maine's hydropower potential concluded that retrofitting existing hydropower facilities could gain 122 MW of additional capacity, but that no sites had a simple payback of less than 20 years (Maine Governor's Energy Office, 2015). Additionally, the study found that significant regulatory obstacles exist in Maine, making new hydropower potentially less attractive for investors.

Currently, projects in the Kennebec and Penobscot Rivers include 31 actively licensed projects which drain more than 40 percent of the state by area. Maine ranks the fifth highest in the nation for the number of hydropower projects requiring relicensing in the next two decades (n=40), necessitating increased participation from stakeholders (Curtis and Buchanan, 2018). Projects in these watersheds exhibit a range of diverse characteristics, ranging in size and purpose. They include larger dams with authorized generating capacity between 13000 and 83700 MW (n=10), smaller dams between 250 and 9000 MW (n=18), and non-generating storage facilities (n=3). They occupy mainstem rivers close to the watershed mouth while others occupy small tributaries farther inland. In terms of ownership, over half of the projects (58%) are licensed and operated by subsidiaries of Brookfield Renewable Partners, one of the world's largest publicly traded renewable energy developer. This is followed by 26% held by large private corporations with the remaining projects held by small private corporations and conservation organizations. A variety of fish species exist within project boundaries and the fish passage measures that are negotiated and enforced vary from project to project. In particular, decision-making often centers around fish passage implementation and fishery conservation.

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.

These rivers have been the site of notable conservation efforts and basin-scale planning initiatives. Several noteworthy changes to these river systems have occurred due to this conservation-driven approach. 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 project, opening 30 km of habitat and eliciting other improvements to fish passage, including several other dam removals. The Penobscot River Restoration Project, started in 1999, was a collaborative effort to balance fish restoration and hydropower production that involved conservation organizations, state and federal resource agencies, and three licensees. A major outcome of the project was the removal of two hydropower dams and increased fish passage at another, improving access to 3200 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. The diversity in the Kennebec and Penobscot River watersheds makes insight into agency decision-making transferable to other projects that exhibit similar characteristics.

2. Citation Analysis

We used citation analysis in tandem with an online stakeholder survey. This mixed methods approach followed a convergent, parallel design 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, 2007) 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). For example, longer bibliographies and diverse citations have been linked to thorough literature reviews while the presence of many peer-reviewed sources may indicate a reliance on information that has reviewed through a standardized validation process. Similarly, we assumed that stakeholders closely aligned in management would exhibit similar citation profiles with one another. It is important to note that this research does not attempt to directly link individual citations to ultimate management decisions. Rather, we used citations as a proxy for the information that document authors found necessary to frame and support their narrative.

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.

2.1. Methods

Only 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 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. While not necessarily indicative of BAS, citation age was used to further describe information use within the system and possibly highlight information gaps such as the absence of information within a certain time period. Additionally, "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 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

2.2. Results

Among the 62 analyzed documents, a total of 5044 individual citations were identified. The median 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). 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 and Figure 1).

The use of information sources was found to differ by document author (χ^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). 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).

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

Table 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*)

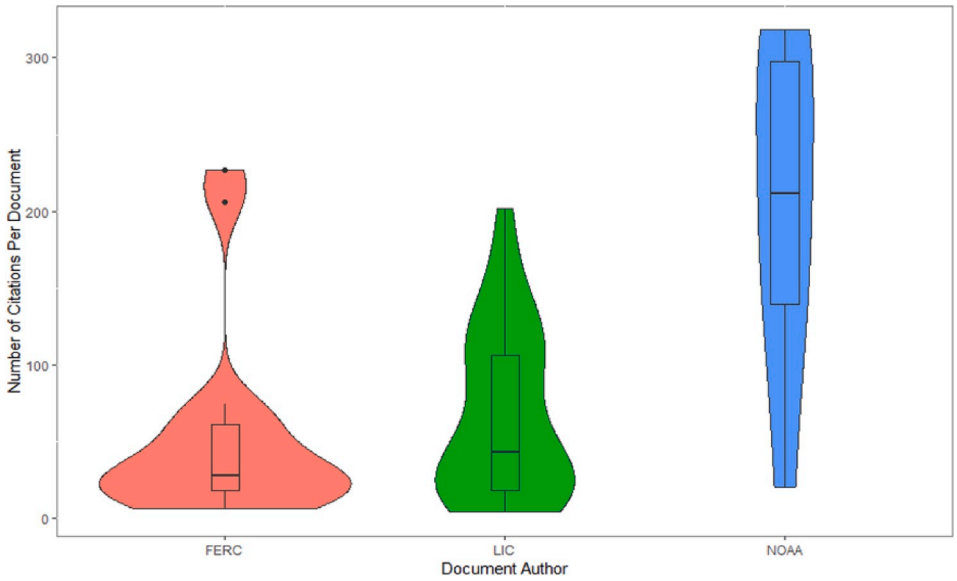

Figure 1. Citations per document. Violin plots visualizing the distribution of the average number of citations per hydropower licensing document. Documents were derived from the Kennebec and Penobscot River projects in Maine that underwent licensing from 2000-2018. Plots are partitioned by document authors, representing FERC, licensees, and NOAA, respectively. The mean, 95% CI, and SD are indicated by internal box plots.

documents (mean = 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.

3. Stakeholder Survey

3.1. Methods

Using the citation analysis to guide our inquiry, we developed a stakeholder survey to characterize how federal and state resource agency members define and operationalize BAS in their own words. We used a non-proportional, purposive sampling method (Etikan et al., 2016; Lavrarkas, 2008) in an online survey to invite individuals from agencies involved in the regional relicensing process. Unlike our citation analysis, this included two federal resource agencies (NOAA and USFWS) and three state agencies (MDEP, MIFW, and MDMR). Although the mandatory licensing documents used in our citation analysis did not include any State of Maine-authored documents, we found it important to include state agency members in our survey. State agencies have specific influence in the relicensing process related to water quality certification and fishery management and offer a unique perspective on local resource 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.

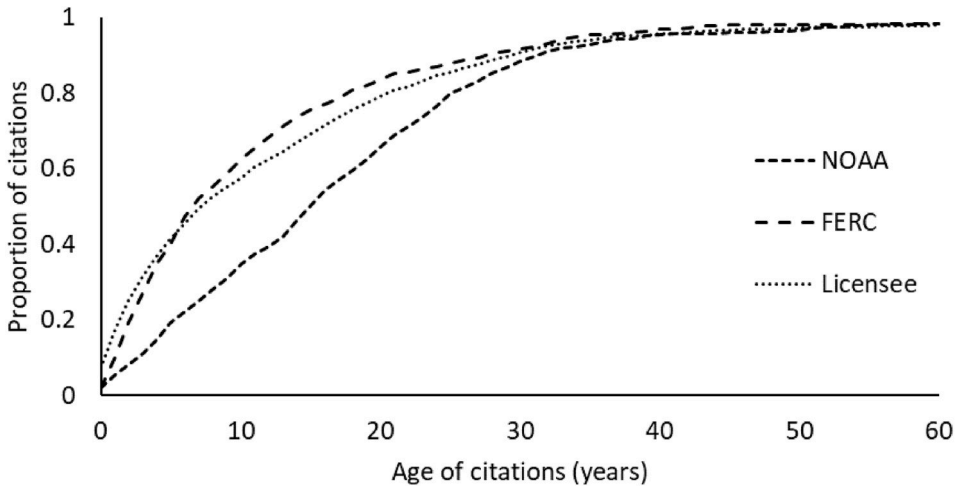

Figure 2. Citation age. Relative age of the citations used by NOAA Fisheries, FERC, and licensee authors in hydropower relicensing documents.

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 employ"* 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"*). In addition to combined federal and state agency sources (agency grey literature), peer-reviewed publications, unpublished academic research (e.g., theses), and industry reports, 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 included. 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.

3.2. 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 3 and Table 3). Peer-reviewed and academic sources received a higher BAS score from federal respondents ($p < 0.001$; Table 3). Conversely, expert sources received a higher BAS score from state respondents ($p < 0.05$). 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 ($p < 0.05$; Table 3), the remaining five sources did not show a difference.

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 ($p < 0.001$; Table 3). Conversely, state respondents reported using expert sources more often ($p < 0.05$; Table 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 3). State respondents as a group, were in high agreement of their use of industry sources relative to federal respondents ($p < 0.05$).

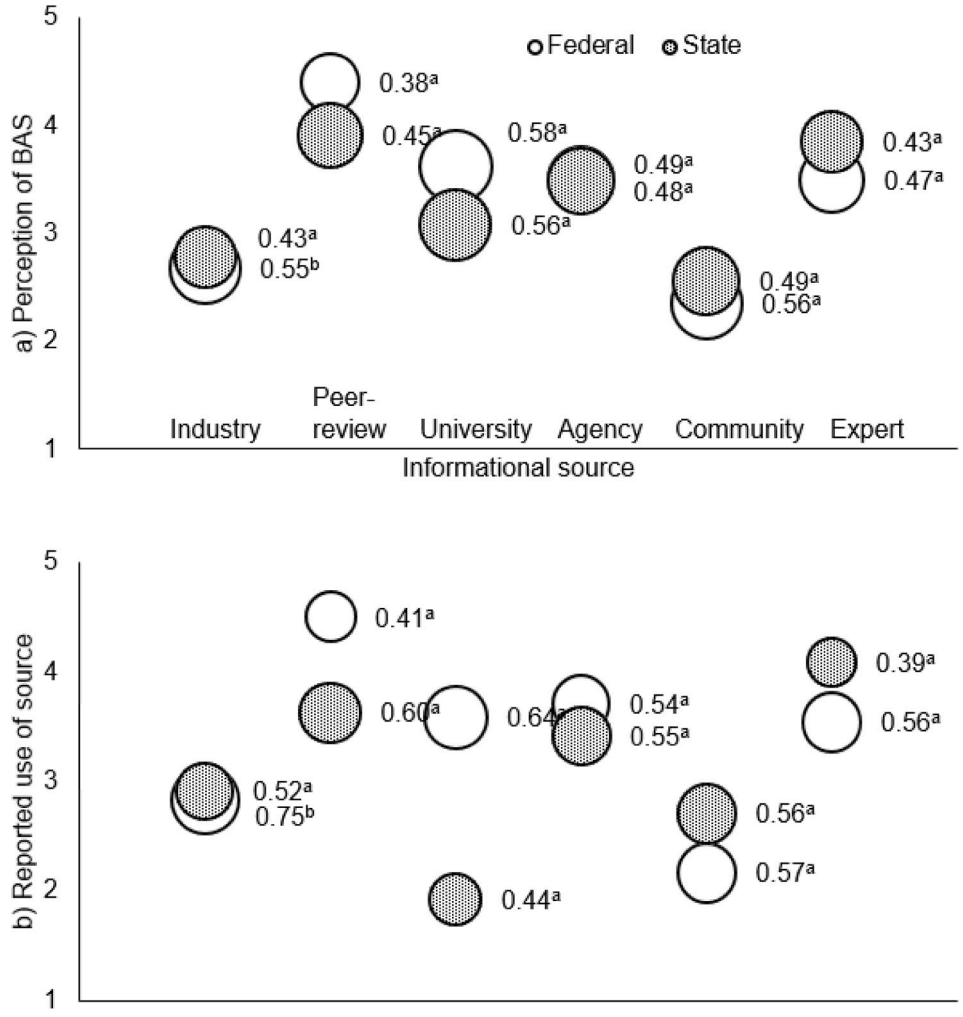

Figure 3. Perceptions and use of BAS. BAS Index rankings of six informational sources in terms of (a) perceptions of BAS compared to (b) their reported use by federal and state resource agency survey respondents. The middle of each bubble represents the mean response. The size and numbers listed for each bubble represent the PCI_2 value. The superscript letters indicate statistical differences at $p < 0.05$. PCI_2 values range from zero to one, indicating complete consensus to no consensus.

Table 3
BAS Index. Differences in the perceptions of best available science and use of six informational sources used by federal and state resource agency survey respondents.

	Resource agency			
	Federal (51%)	State (49%)	p	η^2
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 $p < 0.001$

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."*

4. Conclusions and Policy Implications

We found considerable variation in the informational sources that NOAA, licensees, 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). A comparative analysis of NOAA and USFWS ESA decisions in 2016 similarly found that NOAA rates highly in terms of BAS, outperforming USFWS in having a higher diversity of author types and a higher proportion of peer-reviewed literature (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, 2007). 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) and citation age (Figure 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 document, it 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). While not inherently problematic, this anchoring may detract from the concerns of other stakeholders and make it more difficult to comprehensively address all relicensing objectives.

Similarly, licensee generated Draft Biological Assessments 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 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 licensing process. Additionally, it is difficult to link the impact of specific citations to final management decisions. While the analysis addresses the sources and quantity of citations as a proxy for BAS, it cannot determine what is ultimately used and the relative importance of each citation. For example, some information may be included purely to provide context about a project and may not have direct bearing on decision-making. However, the case may be made that all information, including framing information, affects the evaluation and choices of decision makers.

Finally, 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; 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. With few exceptions, most individuals assumed relicensing responsibilities in addition to their other organizational responsibilities. 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 3 and Figure 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 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 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 [USA]."* Additionally, 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.

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 and community comments. In comparison, federal respondents, with a larger regulatory scope, tended to use more traditional academic sources (Table 3). Increasingly accepted, are concepts of the water-energy-food nexus to address water, energy, and food resource challenges in the face of climate change, population growth, and globalization (Endo et al., 2017). This calls for increasingly transdisciplinary cooperation and management to address increasingly complex problems. Inherent to this concept is the importance of diverse stakeholder input and context specific knowledge.

For the most part, there was a similar degree of consensus among respondents irrespective of organizational affiliation (Figure 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 PCI2 values), especially for agencies governed by institutional and statutory guidelines promoting BAS (Figure 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 and Alabama Rivers Alliance, 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.

It may be noted that the interpretation of BAS, as well as the enforcement of conservation-driven regulation, is not static through time. 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.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Sarah K. Vogel: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing - original draft. **Jessica S. Jansujwicz:** Methodology, Resources, Writing - review & editing. **Carly C. Sponarski:** Methodology, Writing - review & editing. **Joseph D. Zydlewski:** Methodology, Resources, Writing - review & editing.

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S. Government.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2020.111457.

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