Evaluating Dam Relicensing and River Herring Habitat Restoration from a Broad, Multi-Ecosystem Perspective

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An Honors Project for the Program of Environmental Studies

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Abstract

This study investigates the potential benefits of using a broad, multi-ecosystem analysis in the licensing and relicensing of hydropower facilities. Specifically, it considers the impact of river herring restoration on coastal food webs and cod and other groundfish populations in the Gulf of Maine. The past two decades of research on fisheries management, ecosystem connectivity, and the connection between river herring and groundfish in the Gulf of Maine have resulted in a better understanding of the ways in which human activities, such as dam building, influence ecological processes. The paper analyzes two case studies of six Maine dams currently engaged in the Federal Energy Regulatory Commission's (FERC) hydroelectric dam relicensing process. The analysis illustrates the shortcomings of the Federal Power Act's provisions that address the balancing of ecological and power generation concerns. Following the case studies, a series of policy recommendations are presented to encourage a more transparent and predictable relicensing process that adequately values both ecological and power generation goals. Changes are suggested for both the FERC process itself and the process by which state and federal resource agencies may provide comments regarding how a proposed dam licensing or relicensing affects natural resources under their jurisdiction. The proposed policy recommendations will increase the resilience of natural systems as they adapt to climate impacts.

Keywords: river herring, cod, dams, dam removal, hydropower, Gulf of Maine

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Important Terminology

ASMFC	Atlantic States Marine Fisheries Commission
Developmental asset	An asset related to the development of a hydropower facility, namely power generation
DEP	Department of Environmental Protection
DMR	Department of Marine Resources
EBM/EBFM	Ecosystem-Based Management/Ecosystem-Based Fisheries Management
ECPA	Electric Consumer Protection Act

FERC	Federal Energy Regulatory Commission
Fish passage infrastructure	Any infrastructure on and around dams meant to facilitate upstream and downstream passage for anadromous species. Options include fish lifts and ladders with a series of pools and dividers on a shallow gradient over the dam. Other options are trap and truck programs which capture fish below dams and transport fish upstream in trucks
FPA	Federal Power Act
FWS	United States Fish and Wildlife Service
Generation capacity	Maximum generating capacity of a dam based on equipment and FERC limits. Dams are rated with a generation capacity in MW and measure yearly output in MWh
IFW	Maine Department of Inland Fisheries and Wildlife
MW	Metric for energy generation and consumption equal to one million watts
MWh	Metric for energy generation and consumption equal to one MW generated or consumed for one hour
NMFS	National Marine Fisheries Service
Non-developmental asset	An asset unrelated to the development of a hydropower facility: environmental, recreational, and scenic value
Resource Agency	A government agency responsible for management of resources. Specific to the FERC process, this includes any agency with a jurisdiction over natural resources impacted by FERC relicensing decision.

Introduction

Maine's abundant aquatic resources shape life in the state, providing important benefits including hydropower, transportation, seafood, and more. Native Americans were the first humans to make use of Maine's plentiful seafood and water resources by establishing settlements nearby resource-rich areas.[1] When Europeans began colonizing Maine, fishing off the coast quickly dominated life as the Gulf of Maine offered untold bounties to be cured, salted, and shipped across the Atlantic Ocean to European markets. Reports from fishermen regularly reference catching oysters the size of dinner plates, cod larger than the fishermen themselves, and limitless abundance.[2] Today, with the exception of the lobster fishery, most historical commercial fisheries in the Gulf of Maine are suffering the consequences of centuries of heavy fishing pressure, warming waters due to climate change, and fractured connections between ecosystems.[3,4] The final collapse of the groundfishery, beginning with cod in 1992, brought economic devastation to fishermen and others involved in the industry, from fish processors to residents who harbor deep pride in the local, fresh seafood of the Gulf of Maine. Prior to the collapse, fisheries managers were involved in tense planning initiatives with fishermen. While scientists were warning about an imminent population crash, fishermen argued that the record catches in their nets meant that the scientists were mistaken, resulting in a deadlock that ended when the fishery collapsed spectacularly. The response of fisheries managers to the collapse was predictable: they closed areas of the Gulf of Maine to fishing, implemented strict catch limits,

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[1] Jill Foran, *Maine: The Pine Tree State*, Discover America (New York, NY: AV2 by Weigl, 2016), 5.
[2] Penobscot Marine Museum, "History of Fisheries in Maine," Educational, 2012, https://penobscotmarinemuseum.org/pbho-1/fisheries/history-fisheries-maine.
[3] T. Hennessey Healey M., "Ludwig's Ratchet and the Collapse of New England Groundfish Stocks," *Coastal Management* 28, no. 3 (July 2000): 188, https://doi.org/10.1080/089207500408629.
[4] Jonathan A. Hare et al., "A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf," ed. Jan Geert Hiddink, *PLOS ONE* 11, no. 2 (February 3, 2016): 15, https://doi.org/10.1371/journal.pone.0146756.

and many fishermen were forced out of the industry for financial reasons. The strict measures in response to the collapse have yet to yield significant results in recovery of groundfish populations and the industry is still a shell of its former self. Looking at the response, one might conclude that managers did not sufficiently limit fishing or that a longer, more restrictive closure is required for cod and other groundfish to recover and sustain larger harvests.

But what if the collapse was caused, at least in part, by factors beyond the traditional scope of fisheries management? What if the collapse of the cod fishery, and subsequent failed recovery, was partially unrelated to fishing pressure? Research over the past two decades indicates that there is an important ecological connection between groundfish and river herring. River herring are two similar anadromous fish species that play an essential role in the diet of cod and other groundfish, specifically in relation to the maturation of juvenile cod.[5] Since the colonial era, river herring populations have experienced a significant decline in abundance due to overfishing and construction of dams throughout Maine's watershed that block access to upstream spawning grounds. Collapsed populations of river herring changed the Gulf of Maine's food web by removing an important source of forage from the lower tiers of the food web and deprived cod and other species of an important source of protein and fat. Research demonstrates the importance of food webs with multiple connections among trophic levels in making ecosystems more resilient to shocks and enabling faster recovery from disturbances.[6] Without recovery of river herring, efforts to restore cod populations using limits on harvests are unlikely to succeed, as has been the case for the past three decades.

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[5] Edward P. Ames and John Lichter, "Gadids and Alewives: Structure within Complexity in the Gulf of Maine," *Fisheries Research* 141 (April 2013): 76, https://doi.org/10.1016/j.fishres.2012.09.011.
[6] Simon A. Levin and Jane Lubchenco, "Resilience, Robustness, and Marine Ecosystem-Based Management," *BioScience* 58, no. 1 (January 1, 2008): 28, https://doi.org/10.1641/B580107.

One of the biggest factors holding back any significant recovery for river herring are dams: Maine has a significant number of dams throughout the state on major waterways and small tributaries. These dams provide a number of benefits including flood control, recreational activities, and hydroelectric power generation. Dams also block upstream migration for anadromous species that require access to freshwater spawning habitat in lakes and ponds to complete their life cycle. In terms of impacts on river herring, the most significant dams are large dams on major waterways, many of which are hydroelectric generation stations and are regulated under the Federal Power Act by the Federal Energy Regulatory Commission (FERC) for 30-50 year terms.

This study investigates the potential benefits of using a broad, multi-ecosystem analysis in the licensing and relicensing of hydropower facilities. Specifically, it considers the impact of river herring restoration on coastal food webs and cod and other groundfish populations in the Gulf of Maine. The past two decades of research on fisheries management, ecosystem connectivity, and the connection between river herring and groundfish in the Gulf of Maine have resulted in a better understanding of the ways in which human activities, such as dam building, influence ecological processes.

This paper begins with a review of the historical intersection between dams and anadromous species in New England. This section covers the history of river herring in New England, the various anthropogenic uses of river herring, and background about dam construction from the 17th century to the present. After establishing this background, the federal dam regulatory structure is discussed, specifically the role of the Federal Energy Regulatory Commission (FERC) in the dam relicensing process. The section concludes with information about the State of Maine's energy profile, the current climate action plan, and an overview of renewable energy technological developments, such as wind and solar.

The next major section explores two case studies of previous dam removal efforts in Maine to establish the role of dams in obstructing ecosystem flow and demonstrate the impact of removal on anadromous species. The findings from the Previous Removal case studies are then used in case studies of six dams up for relicensing on two rivers in Maine. The FERC process currently undervalues ecological concerns due to vague language in the relevant provisions. The vague language results in decisions that do not adequately balance developmental and non-developmental concerns. The paper culminates in a review of four key provisions of the FPA that address ecological concerns and contains recommendations to make the FERC decision making process more transparent while ensuring that ecological concerns are given equal consideration to those of power generation.

History of Dams, River Herring, and other Anadromous Species in New England

River herring are an important species in both river habitats and the Gulf of Maine ecosystem. The term river herring refers to alewife (*Alosa pseudoharengus)* and blueback herring (*Alosa aestivalis),* anadromous fish species native to the Gulf of Maine and river systems of New England.[7] They are an important source of forage for various species including cod, haddock, and other groundfish, and benefit endangered Atlantic salmon by providing migrating smolt with a prey buffer. After centuries of dam building and habitat destruction, current estimates put river herring populations between 1% and 8% of historic levels.[8] Importantly, they

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[7] State of Maine Department of Marine Resources, "Maine River Herring Fact Sheet" (Maine: Department of Marine Resources, n.d.), https://www.maine.gov/dmr/science-research/searun/alewife.html.
[8] Carolyn J. Hall, Adrian Jordaan, and Michael G. Frisk, "Centuries of Anadromous Forage Fish Loss: Consequences for Ecosystem Connectivity and Productivity," *BioScience* 62, no. 8 (August 2012): 725, https://doi.org/10.1525/bio.2012.62.8.5.

are species with highly compensatory population dynamics that respond well to habitat restoration. In turn, the restoration will aid in the recovery of other species such as cod and Atlantic salmon, two species that are currently collapsed in the Gulf of Maine.[9] River herring and other anadromous fish rely on three different, but connected, ecosystems throughout their lifecycle: marine ecosystems, where adults spend most of their year; estuarine ecosystems, a nursery habitat for young-of-year fish; and freshwater ecosystems, where adults spawn and juveniles spend their first few weeks or months. Other species of anadromous fish present in Maine waters include American shad (*Alosa sapidissima)*, Atlantic salmon (*Salmo salar)*, rainbow smelt (*Osmerus mordax)*, Atlantic tomcod (*Microgadus tomcod)*, sea lamprey (*Petromyzon marinus)*, shortnose sturgeon (*Acipenser brevirostrum),* Atlantic sturgeon (*Acipenser oxyrhynchus)*, and striped bass (*Morone saxatilis)*.[10] In addition to the ecological value of these anadromous species, many also have commercial and recreational value such as the commercial river herring fishery and the recreational striped bass fishery. Adult river herring journey upriver from early May through June, making their way to ponds and lakes to spawn before returning downriver to the ocean.[11] Newly hatched river herring are left to survive on their own before beginning their journey to the ocean in the summer and fall months, typically between July and November. They congregate in the mouths of large river systems and provide a food source for cod and other groundfish, which is especially important for maturing juveniles of these species.[12]

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[9] Anne Hayden, Medea Steinman, and Rachel Gorich, "Up and up: River Herring in Eastern Maine" (Downeast Fisheries Partnership, 2019), 2.

[10] "Penobscot River Fisheries," *Natural Resources Council of Maine* (blog), November 28, 2018, https://www.nrcm.org/programs/waters/penobscot-river-restoration-project/penobscot-river-fisheries/.

[11] State of Maine Department of Marine Resources, "Maine River Herring Fact Sheet."

[12] C.G. Atkins, "The River Fisheries of Maine," in *Goode, B.g. et al. The Fisheries and Fishery Industries of the United States*, vol. 1, n.d., 685–88.

It is difficult to describe historic river herring abundance with certainty because preserved written records only exist for 5% of the 8,600 year period of human habitation of New England.[13] Archeologists estimate that river herring and other anadromous fish were present in Maine at least 6,000 years ago; radiocarbon dating techniques indicate that a fish weir found in Sebasticook Lake was present in the year 4,000 B.C.E.[14] There are some important historical sources that can be used to estimate river herring populations and abundance during the last 400 years of European colonization. Harvest records date back to 1950. Before then, sporadic fisheries reports from various agencies, oral histories from Native American tribes, and other miscellaneous evidence may be used to establish an estimate of historic populations. Native Americans were the first people to take advantage of yearly river herring runs to harvest fish rich in protein and fats.[15] Research indicates that river herring were an abundant resource with "archeological evidence of Native villages along the Nemasket River at sites where river herring were most easily harvested."[16] This evidence of native use and the abundance of river herring is corroborated by Captain John Smith's account of his time in New England, saying "that in Aprill there is a fish much like a Herring that come up into the small Brookes to spawne… in such abundance as is incredible [sic]."[17] These and other historical records indicate that river herring were very abundant throughout New England before European colonization beginning in the early seventeenth century.

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[13] Douglas Watts, *Alewife: A Documentary History of the Alewife in Maine and Massachusetts* (Poquanticut Press, 2012).
[14] Douglas Watts.
[15] Heike K. Lotze and Inka Milewski, "Two Centuries of Multiple Human Impacts and Successive Changes in a North Atlantic Food Web," *Ecological Applications* 14, no. 5 (2004): 1431–32.
[16] Barbara Brennessel, *The Alewives' Tale: The Life History and Ecology of River Herring in the Northeast* (University of Massachusetts Press, 2014), 2.
[17] Captain John Smith, "The General Historie of Virginia, New England, and the Summer Isles," in *Writings, with Other Narratives of Roanoke, Jamestown, and the First English Settlement of America* (New York: Library of America, 2007), 211.

More detailed records regarding river herring are available from the second half of the seventeenth century. Atkins' and Fosters' "First Report of the Commissioners of Fisheries of the State of Maine" presents observations about the status of fish populations; the sections concerning river herring state that "[v]ast numbers [of river herring] once swam in all suitable waters through the State."[18] A witness account in the report describes a fall run of juveniles as "proceed[ing] in a dense column, frequently miles in length."[19] These descriptions further indicate that river herring population numbers were significantly higher before detailed record keeping began in 1950.

River herring harvest data are available from the 1950s to the present and are a helpful proxy for determining the status of river herring populations. The river herring fishery in Maine and New England was a productive fishery for decades. River herring were harvested for human consumption, both personal and for trade, and as bait. River herring were consumed fresh and salted, pickled, and smoked for consumption throughout the year.[20] River herring were commonly used as bait for both lobster and groundfish as well as fertilizer for crops; river herring fisheries supported many harvesters over the decades. Today, river herring are primarily sought out as bait in the lobster and halibut fisheries but landings are well below historic levels.

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[18] Charles Atkins and Nathan Foster, "First Report of the Commissioners of Fisheries of the State of Maine" (Augusta: Owen and Nash, 1867), 9.
[19] Charles Atkins and Nathan Foster, 11.
[20] Andrew Frank Bigelow et al., *Bigelow and Schroeder's Fishes of the Gulf of Maine*, 3rd ed (Washington, DC: Smithsonian Institution Press, 2002).

Figure 1.

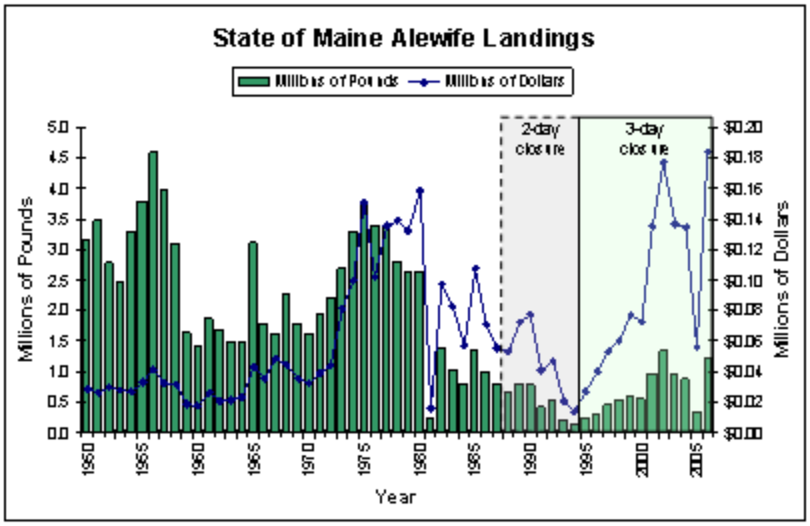

Figure 1. *Alewife landings in millions of pounds and value of the harvest in millions of dollars from 1950-2006 with data collected by the State of Maine Department of Marine Resources. https://www.maine.gov/dmr/science-research/searun/alewife.html*

The harvest data, shown in **Figure 1**, contain important information from the last 70 years and clearly show a decline in landings, mainly from the collapse throughout the 1980s and 1990s. This data, however, is limited by the lack of corresponding catch-per-unit-effort data. As effort affects landings, the decline may be the result of collapsed river herring populations or a drop in fishing effort. The landing data can still be used as a rough approximation of abundance. Other data points, such as counts of migratory fish, can be used in conjunction with landing data to better understand the ecological reality. The decline shown in **Figure 1** is a continuation of a larger decline that began when Maine's rivers were first dammed in the seventeenth century by settlers to power mills and other infrastructure.

On a map, New England's landscape has changed very little throughout the past 400 years, since the beginning of European colonization. The Androscoggin River still flows from Northern Maine, through part of New Hampshire, back into Maine through Lewiston and Brunswick before emptying into the Gulf of Maine via Merrymeeting Bay. The Kennebec, Penobscot, and St. Croix rivers also track paths identical, or very similar, to the routes that existed when European settlers arrived and well before that, too. What the maps do not show is the changes in river flow that resulted from the industrial development of rivers. Rivers were dammed and diverted to generate power for and serve Maine's lumber, textile, and other industries. Dams disrupt the free flow of rivers, alter river composition by affecting turbidity and dissolved oxygen levels, and impede the upstream passage of aquatic organisms such as river herring and other anadromous fish.[21]

To understand the true impacts of dams on river ecosystems, it is useful to explore the history of human use of Maine's river systems. Native Americans used weirs to harvest river herring and other fish for sustenance and fertilizer. Maine was colonized by Europeans beginning around 1607 and communities were quickly established on rivers such as the Kennebec; river access facilitated travel, fishing and hunting.[22] Dam building by Europeans in Maine began soon after colonization to power grist mills and other infrastructure, control flooding, and harness the river's power.[23] The rivers were used by logging companies to drive logs downstream to sawmills located on water's edge and powered initially by diverting the river to flow over water wheels. Dams were built to control the flow of rivers to suit the needs of industry.[24]

Without a detailed knowledge of ecosystem function or any regulatory oversight, early infrastructure projects dammed rivers indiscriminately. Carolyn Hall described the history of dam building in Maine from 1600 to the present; the first major dams were constructed on the

[21] Carolyn Jean Hall, Adrian Jordaan, and Michael G. Frisk, "The Historic Influence of Dams on Diadromous Fish Habitat with a Focus on River Herring and Hydrologic Longitudinal Connectivity," *Landscape Ecology* 26 (February 23, 2010): 96, 106.
[22] Foran, *Maine*, 5.
[23] Foran, 5.
[24] James Elliott Defebaugh, *History of the Lumber Industry of America*, vol. 2 (The American Lumberman, 1907).

Salmon Falls River and the York River in 1634.[25] Dam building accelerated over time, with every major river system in Maine having at least one dam by 1828 and multiple dams by the end of the nineteenth century.[26] Hall's analysis found that dam building throughout the seventeenth and eighteenth centuries severely limited access to inland ponds and lakes for anadromous fish populations. Head-of-tide dams, constructed at or near the limit of tidal influence, reduced access to streams by 7-59%; the construction of the Edwards Dam at the head-of-tide on the Kennebec River reduced access for anadromous fish to less than 1% of the watershed's historically available spawning habitat in lakes and ponds.[27] This widespread development on river systems throughout Maine devastated anadromous fish populations because reduced access to spawning grounds dramatically impacted species productivity. In the period between 1634 and 1850, dam construction for mills throughout Maine reduced river herring access to spawning grounds by 95%.[28] Unfortunately, because abundance or harvest data for river herring are unavailable for this period, it is impossible to know exactly how much impact dams had on populations, and it is difficult to track population decline for this period. There are records from historical reports that attribute population declines in anadromous species to two major causes: dam building and overfishing.[29] These reports, such as Foster and Atkins' 1887 report on the state of fisheries in Maine, reveal early knowledge about the impact of dams, but little came of these observations.

Dam building continued throughout the decades with no organized regulation of location, fish passage infrastructure, or impacts of dams on the surrounding ecosystem. In the

[25] Carolyn Jean Hall, Adrian Jordaan, and Michael G. Frisk, "The Historic Influence of Dams on Diadromous Fish Habitat with a Focus on River Herring and Hydrologic Longitudinal Connectivity," 100.
[26] Carolyn Jean Hall, Adrian Jordaan, and Michael G. Frisk, 100.
[27] Carolyn Jean Hall, Adrian Jordaan, and Michael G. Frisk, 101–2.
[28] Carolyn Jean Hall, Adrian Jordaan, and Michael G. Frisk, 103.
[29] Charles Atkins and Nathan Foster, "First Report of the Commissioners of Fisheries of the State of Maine."

late nineteenth century, developments in technology from Thomas Edison and others enabled electrical energy to become an important power source. According to the Maine Historical Society, within a year of these developments, there was at least one mill in Maine that used electricity to power lights and mill owners quickly recognized the benefits to be gained by hydroelectric generation.[30] Hydropower was not only an efficient way to power riverside infrastructure but to provide power to cities and towns as electrical transmission became more feasible with each passing year. Hydropower presented a valuable economic opportunity independent of the mills. By the end of the nineteenth century, hydroelectric generation was an important resource for the growing electrical grid in Maine as entrepreneurs envisioned a "wonderful transformation if electric power were harnessed to each industrial wheel in the state."[31] This realization spurred a wave of development across Maine and the rest of New England as small dams were modified to fit into the growing patchwork electrical grid and large corporations, such as Bangor Hydro-Electric, Gould Electric, and Central Maine Power, rose to prominence.[32] As these companies gained influence due to rising demand for power, development increased and large dam projects were undertaken throughout the state of Maine at the beginning of the nineteenth century. This reflects societal priorities of the time: the value of instream flows and ecosystem function were less well understood than they are today, particularly in relation to the demand for power. Rapid development occurred with little understanding of river ecosystems and the organisms that rely upon them, contributing to the eventual collapse of anadromous fish populations.

By the time federal legislation was passed to regulate dam construction and use, the

[30] Maine History Online, "1870-1920: The End of the Ocean Highway" (Maine Historical Society, n.d.), https://www.mainememory.net/sitebuilder/site/905/page/1316/display?page=6.
[31] Maine History Online.
[32] Maine History Online.

majority of dams in Maine had already been constructed. Regulations were implemented at the end of the nineteenth century and are still being modified today. Dams are privileged over other concerns due to their long-term presence on the river instead of approaching each relicensing process from a neutral standpoint. This is a problem when making decisions for ecological purposes because regulators do not have a dam-free baseline to base decisions on. This project focuses on the relicensing aspect of dam regulation due to very few, if any, new dams being built because suitable locations are already dammed.

It is important to recognize that the regulatory process should be updated regularly to best align with current scientific knowledge and to provide the best possible balance between competing interests. The balance between competing interests changes over time due to shifting social preferences and the availability of alternative technologies. Ecological concerns about river health were not a part of the discourse until relatively recently. Changing preferences impact how decisions are made and what trade-offs are deemed acceptable to decision makers and stakeholders. It is not a realistic goal to revert to a dam-free landscape: dams play important roles in flood control, water management, power generation, and recreational activities throughout the world. Their role in power generation is vital to the state of Maine's renewable energy generation goals, although that reliance is dropping as alternative forms of renewable energy become increasingly feasible on large scales. This project focuses on the ecological impacts of dams from a multi-ecosystem perspective to balance the benefits of hydroelectric generation with the costs to the ecosystem.

Dam Regulation and Licensing

Today, the majority of dams are subject to federal or state regulation. The primary goal of the Rivers and Harbors Act of 1899, the first federal effort to regulate dams, was to preserve the navigability of rivers and streams; permits were required to build dams but were issued with little restraint.[33] In 1920, Congress sought to regulate the generation of hydroelectricity by passing the Federal Water Power Act. Successive amendments, including the Department of Energy Organization Act of 1977, renamed the legislation as The Federal Power Act and created the Federal Energy Regulatory Commission (FERC).

FERC is responsible for regulating the construction and oversight of hydroelectric dams; successful applicants are issued renewable 30-50 year licenses.[34] Originally, the licensing process was primarily concerned with ensuring dams were constructed and maintained to appropriate safety standards while serving the public interest in power generation.[35] Subsequent updates to the Federal Power Act reflect growing concern regarding the environmental impact of dams but do not guarantee that ecological considerations are balanced with other goals. The passage of the Electric Consumers Protection Act of 1986 (ECPA) updated the Federal Power Act to expand FERC's regulatory oversight regarding riverine organisms (**Table 1**). Under this amendment to the Federal Power Act, FERC is required to consider the health of anadromous fish populations when licensing or relicensing a dam.[36] The amendment "require[s] FERC to give 'equal consideration to the purposes of energy conservation, the protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities and the preservation of other aspects of environmental quality.'"[37] By requiring the "equal consideration" of the interests of power

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[33] Andrew Franz, "Crimes Against Water: The Rivers and Harbors Act of 1899," *Tulane Environmental Law Journal* 23, no. 2 (2010): 256.
[34] Center for Regulatory Effectiveness, "Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service," n.d., https://www.thecre.com/about.html.
[35] Marla Barnes, "Tracing the TImeline: 101 Years of the Federal Power Act" (NHA Powerhouse, June 7, 2021), https://www.hydro.org/powerhouse/article/tracing-the-timeline-101-years-of-the-federal-power-act/.
[36] Marla Barnes.
[37] Hydropower Reform Coalition, "Federal Power Act (FPA)," 2022, https://hydroreform.org/resource/federal-power-act-fpa/.

generation and environmental health, FERC's responsibilities expanded in regard to protecting anadromous fish and their habitats. The ecological considerations in the FPA are not binding, unlike the binding provisions of the Endangered Species Act, which compel action related to the species in question regardless of competing interests or conflicting goals. There are four provisions in the amendments from the ECPA which address ecological considerations when making licensing decisions: section 4(e) establishes the "equal consideration" component, sections 10(a) and 10(j) address comments from resource agencies, and section 18 enables FERC to require construction of fish passage infrastructure. Under the ECPA amendments, FERC must balance the impacts of the dam on the surrounding and connected ecosystems, the public interest in power generation from the dam, and the perspective of resource agencies in federal and state governments.

Table 1. ECPA Amendments to the FPA

Section 4(e)	"In deciding whether to issue any license under this Part for any project, the Commission, in addition to the power and development purposes for which licenses are issued, shall give equal consideration to the purposes of energy conservation, the protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality [emphasis added]."[38]
Section 10(a)	FERC shall ensure that plans are "best adapted to a comprehensive plan for improving or developing a waterway or waterways for the use or benefit of inter- state or foreign commerce, for the improvement and utilization of waterpower development, for the adequate protection, mitigation, and enhancement of fish and wildlife (including related spawning grounds and habitat), and for other beneficial public uses, including irrigation, flood control, water supply, and recreational and other purposes referred to in section 4(e)"[39]
Section 10(j)	That in order to adequately and equitably protect, mitigate damages to, and enhance, fish and wildlife (including related spawning grounds and habitat) affected by the development, operation and management of the project, each license issued under this Part shall include conditions for protection, mitigation, and enhancement. ...[S]uch conditions shall be based on recommendations received pursuant to the Fish and Wildlife Coordination Act (16 U.S.C. 661 et seq.) from the National Marine Fisheries Service, the United States Fish and Wildlife Service, and State fish and wildlife agencies.[40]
Section 18	[FERC] shall require the construction, maintenance, and operation by a licensee at its own expense of such ... fishways as may be prescribed by the Secretary of the Interior or the Secretary of Commerce, as appropriate.[41]

This study specifically focuses on the relicensing aspect of the FERC decision making process. The discussion and the recommendations at the end of the paper are applicable to both the licensing and relicensing processes. The focus on the relicensing side of the process is due to the fact that the vast majority, if not all, suitable sites for damming rivers in the United States are

[38] U.S. Congress, "United States Code: Federal Power Act," Pub. L. No. 16 U.S.C. §§ 791-825r (n.d.).
[39] U.S. Congress.
[40] U.S. Congress.
[41] U.S. Congress.

already in use: very few new dams will be built in the foreseeable future due to alternative power sources and awareness of the impacts of dams on freshwater and marine ecosystems.

Fish Passage Infrastructure

Fish passage infrastructure is one way to balance the competing needs of power generation and access to spawning grounds for anadromous fish. Fish ladders and lifts, trap and truck programs, and other tools to facilitate upstream passage are often promoted as a middle ground between using the river for power generation and unimpeded passage for fish. Unfortunately, fish passage efficiency is often low compared to non-obstructed waterways. An analysis of fish passage infrastructure estimated that effective mitigation of habitat fragmentation caused by dams requires fish passage facilities to provide upstream access to 90-100% of migrating fish.[42] A study of existing dams with fish passage infrastructure in New England reported a mean fish passage efficacy of 41.7%, significantly lower than the ideal range.[43] The large gap between ideal and actual passage numbers shows that fish passage infrastructure is not an effective tool in promoting the recovery of anadromous fish populations. Technology that allows 90% passage rates does not currently exist. Additionally, the 41.7% data point does not capture the reality that different species of anadromous fish use fish passage with varying efficiency due to differing preferences for water flow rate.[44] More research and development is necessary for fish passage technology to improve passage efficiency for all species and to more clearly identify the rate of passage required for species restoration.

Current data on fish passage efficiency show that fish passage technology does not

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[42] Michael J Noonan, James W A Grant, and Christopher D Jackson, "A Quantitative Assessment of Fish Passage Efficiency," *Fish and Fisheries* 13, no. 4 (2012): 456, https://doi.org/10.1111/j.1467-2979.2011.00445.x.
[43] Noonan, Grant, and Jackson, 456.
[44] J. Jed Brown et al., "Fish and Hydropower on the U.S. Atlantic Coast: Failed Fisheries Policies from Half-Way Technologies: Fish and Hydropower on the U.S. Atlantic Coast," *Conservation Letters* 6, no. 4 (July 2013): 284, https://doi.org/10.1111/conl.12000.

replicate the passage efficiency of a free flowing river. The difference in passage rates between a free river and a dammed river with fish passage technology suggests that the best practice would be to mandate fish passage technology only in situations where power generation interests outweigh ecological impacts. In practice, however, licensing decisions treat fish passage infrastructure as nearly equivalent to dam removal in terms of its impact on fish passage instead of treating it as a compromise when the dam in question warrants relicensing. This often results in decisions that attempt to achieve the best of both worlds but fail to adequately balance the interests of power generation and ecological health.

Future Power Generation Concerns

In addition to consideration of trade-offs between the ecological benefits of dam removal and the benefits of hydropower, it is important to consider the role of hydroelectric power in the State of Maine's grid. Renewable energy, including hydropower, is increasingly important as a tool to combat global warming. Hydropower generation itself is a non-carbon, renewable source of energy which was one of the only options available on a wide scale prior to the rise of solar and wind power over the past two decades. While hydropower generation does not contribute to climate change, the impacts of dams on the surrounding ecosystem are significant: dams impede sediment flow downriver, block upstream access for migratory species, and can impact local organisms through changes to water temperature and turbidity.[45] Hydropower also has the notable advantage of being a renewable energy source that can be manipulated at will through the use of upstream storage ponds while solar and wind energy currently lack large-scale storage options. Solar and wind energy, however, have undergone significant technological innovation

[45] Brian D Richter et al., "Lost in Development's Shadow: The Downstream Human Consequences of Dams" 3, no. 2 (2010): 29.

over the past half-century and are expected to improve further in the coming decades.[46] Technological developments in storage will make solar and wind energy more realistic to implement on a wide scale. Today, solar and wind power are already more realistic options for grid-scale power than they were during the period when many of Maine's dams were last licensed.

As the United States and the rest of the world begin serious efforts to decarbonize power generation, renewable energy sources such as solar and wind power will make up a growing percentage of energy sources. Maine has an aggressive climate action plan in place, called *Maine Won't Wait*, with the goal of achieving carbon neutrality by 2045 and an 80% reduction of greenhouse gas emissions by 2050.[47] In Maine, hydropower is a very important part of the state's grid, providing about 34% of the state's power.[48] The existing hydroelectric dams throughout Maine provide a valuable resource for a state that is already heavily reliant on renewable energy for the grid: 79% of Maine's electricity generation comes from renewable sources.[49]

A related component of the climate action plan is the goal of increasing the resilience of ecosystems in the face of climate change. Maine's climate goals are inextricably linked to healthy, functioning ecosystems continuing to support economically important industries such as agriculture and fisheries. With hydroelectric generation as the current driver of renewable power in Maine, it is important to be strategic about choices regarding dams without over-prioritizing

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[46] U.S. Energy Information Administration, "Solar Generation Was 3% of U.S. Electricity in 2020, but We Project It Will Be 20% by 2050" (U.S. Department of Energy, November 16, 2021), https://www.eia.gov/todayinenergy/detail.php?id=50357.

[47] Maine Climate Council, "Maine Won't Wait," Climate Action Plan (Augusta: Maine State Government, December 2020), https://www.maine.gov/future/sites/maine.gov.future/files/inline-files/MaineWontWait_December2020.pdf.

[48] U.S. Energy Information Administration, "Maine State Profile and Energy Estimates," 2021, https://www.eia.gov/state/?sid=ME.

[49] U.S. Energy Information Administration.

hydroelectric generation in cases of low power generation. The State of Maine's interest in renewable energy generation and more resilient ecosystems is conveyed to FERC in its comprehensive river management plans and resource agency comments.

When making decisions regarding the relicensing of hydroelectric dams, FERC solicits information related to operational capacity and safety and ecological concerns from a variety of actors including the companies that own the dams, environmental advocacy groups, community stakeholders, related resource agencies, and the general public. Should the dam be denied a license, negotiations are often necessary to fund and facilitate the actual removal process. Below is a table of hydroelectric dams in Maine up for relicensing in the next ten years (**Table 2**). As the table shows, the dams in question generate varying amounts of power for the grid and should be treated accordingly in the licensing process.

Table 2. Dams in Maine Currently Undergoing the FERC Relicensing Process

Project Name	Licensee	File Date (of application for relicensing)	Proposed Capacity (MW)	River
Shawmut	Brookfield White Pine Hydro, LLC	01/31/20	8.74	Kennebec River
Scopan	Algonquin Northern Maine Generating Company	12/03/19	15	Aroostook River
Hiram	Brookfield White Pine Hydro, LLC	11/20/20	11	Saco River
Ellsworth	Black Bear Hydro Partners, LLC.	12/30/15	8.9	Union River
Upper Barker	KEI (USA) Power Management (III), LLC.	07/29/21	0.001	Androscoggin River
Lowell Tannery	Kei (Maine) Power Management (II)	09/28/21	0.001	Passadumkeag River
Pejepscot	Topsham Hydro Partners Limited Partnership (L.P.)	08/31/20	13.88	Androscoggin River

Table 3. Dams in Maine with Licenses Expiring in the Next Decade

Dam	Owner	License Expiration Date	Authorized Capacity (MW)	River
Somersworth	Aclara Meters, LLC.	08/31/2021	2.22	Salmon Falls River
Rollinsford	Rollinsford Town Of	08/31/2021	1.5	Salmon Falls River
Cobscook Bay Tidal Energy	Orpc Maine, LLC.	01/31/2022	0.3	Cobscook Bay
Lower Mousam	Kennebunk Light & Power Dist	03/31/2022	0.6	Mousam River
Lower Great Falls	Green Mountain Power Corp	04/30/2022	1.28	Salmon Falls River
Errol	Brookfield White Pine Hydro, LLC.	07/31/2023	2.031	Androscoggin River
Green Lake	Green Lake Water Power Co	03/31/2024	0.5	Reeds Brook
West Enfield	Bangor-Pacific Hydro Associate	05/31/2024	13	Penobscot River
Hackett Mills	Hackett Mills Hydro Associates	08/31/2024	0.485	Little Androscoggin River
Rumford Falls	Rumford Falls Hydro, LLC.	09/30/2024	44.5	Androscoggin River
Aziscohos	Androscoggin Reservoir Co	03/31/2025	5.311	Magalloway River
Worumbo	Brown Bear Ii Hydro, Inc.	11/30/2025	19.4	Androscoggin River
Lewiston Falls	Brookfield White Pine Hydro, LLC.	08/31/2026	28.44	Androscoggin River
Upper	Lewiston	08/31/2026	1.695	Androscoggin

Androscoggin				River
Penobscot Mills	Great Lakes Hydro America. LLC.	09/30/2026	70.81	Penobscot River (West Branch)
Ripogenus	Great Lakes Hydro America. LLC.	09/30/2026	37.53	Penobscot River (West Branch)
Eustis	Kei ine) Power Mgmt (I) LLC.	11/30/2026	0.25	Dead River (North Branch)
Brunswick	Brookfield White Pine Hydro, LLC.	02/28/2029	19	Androscoggin River
Medway	Black Bear Hydro Partners, LLC.	03/31/2029	3.44	Penobscot River (West Branch)
Cataract	Brookfield White Pine Hydro, LLC.	11/30/2029	6.65	Saco River
Kezar Falls Lower	Kezar Falls Hydro, LLC.	09/30/2030	1	Ossipee River

Discussion of Methods

This study was conducted from September 2021 through May 2022 and relied on certain assumptions to keep the focus narrow and within the constraints of the project's time frame. The first assumption is that the state of Maine will not increase its reliance on hydroelectric power to supply the state's grid as the nation transitions to a cleaner energy portfolio. The second assumption is that demand for energy and energy prices will stay relatively stable in the coming years, significant shifts in either demand or prices will likely have an impact on decision making. The invasion of Ukraine by Russia in February 2022 caused energy prices to rise for fossil fuels which affects the assumption of energy price stability. This change may have a temporary impact on the global energy supply and may result in a faster transition to renewable energy sources or increase the reliance on current renewable sources such as hydropower.

A variety of historical and contemporary sources were used to establish a baseline for comparative purposes and to evaluate the impacts of dams on river herring populations using both qualitative and quantitative data. This process was conducted in the form of an in-depth literature review which focused on five major topics: river herring, dams, coastal food webs, social-ecological systems, and ecosystem-based fisheries management. Peer-reviewed journal articles were found using Google Scholar, Bowdoin OneSearch, and ScienceDirect. Articles were read in detail with key information noted and the works cited were used to find related sources such as articles and books. The cited feature in Google Scholar was used to find recent articles and sources which reference already obtained articles to build a library of sources with the most recent scholarship possible.

In addition to the literature review, quantitative data were collected in the form of publicly available reports, dam licensing and relicensing documents, and disclosures of fish counts, dam energy production, and groundfish surveys. The quantitative data were used as the primary metric for selecting case study dams and with qualitative data used in developing recommendations for policy changes needed to more accurately reflect the ecological impacts of dams on river herring. The primary source of qualitative data used to evaluate case study dams came from publicly available data and both popular and scientific literature. These sources were supplemented with semi-structured interviews with fisheries managers and representatives from nonprofits interested in anadromous fish and dam removal; the interviews were conducted under IRB approval. Dam owning companies, such as Brookfield Renewables, were contacted for interviews but did not respond. Interviewees were selected under consultation of Anne Hayden, this study's advisor, and snowball sampling was undertaken using information from interviewees. Upon receiving consent, interviews were audio-recorded and transcribed for accurate data collection while detailed notes were taken in the event that interviewees did not consent to recording. Interviewees were given the choice to have their name attached to their answers in the final product or be anonymized by the author.

After data was collected through the literature review and interviews, the Social-Ecological Systems (SES) framework was used for analysis and comparison of six dams on two rivers in Maine. Case study dams were compared using the framework advanced by Elinor Ostrom and Michael McGinnis in their update to the original SES framework.[50] The breakdown of second tier variables was used to identify all relevant categories in the case study and to evaluate the trade-offs of relicensing and potential dam removal. This analytical approach is appropriate for assessment of complex systems with both anthropogenic and ecological drivers. It allows for the simultaneous examination of the impacts of dams on the environment in the form of fish passage and ecosystem connectivity as well as stakeholder concerns regarding water levels, boating access, recreational activities, property values and other impacts of dams on municipalities.

Edwards Dam and Penobscot River Restoration Project Case Study

Research conducted in the wake of major dam removals, such as the Edwards Dam on the Kennebec River and the Penobscot River Restoration Project, reveals the benefits of free-flowing rivers by demonstrating the rapid and large-scale positive impact of dam removals on populations of anadromous fish species. This case study examines the ecological impact of dam removals on the Kennebec and Penobscot Rivers at a basin-scale and on related ecosystems. This

[50] Michael D. McGinnis and Elinor Ostrom, "Social-Ecological System Framework: Initial Changes and Continuing Challenges," *Ecology and Society* 19, no. 2 (2014), https://www.jstor.org/stable/26269580.

analysis will be used to consider whether or not the addition of a multi-ecosystem perspective to the FERC relicensing process better complies with the mandates in the FPA to give "equal consideration" to developmental and non-developmental assets and enables regulators to more effectively analyze the costs and benefits associated with dams.

The Edwards Dam on the Kennebec River was the subject of debate over the impact of dams on anadromous species and the balance between power generation and other interests. Finding creative solutions to complex problems is a key step to balancing the trade-offs between the ecological health of free flowing rivers and economic contributions and other public benefits of dams. This process was essential for the removal of the Edwards Dam on the Kennebec River during the 1990s. The dam, located in Augusta, was constructed in 1837 to create a reservoir for log drives and to power local mills.[51] This action was disastrous for the river ecosystem as it eliminated upstream access for the millions of striped bass, shad, Atlantic salmon, sturgeon, alewives, and blueback herring that relied on the river for access to spawning grounds, leaving only 17 miles of river accessible out of the total 170 mile length of the river.[52] When the dam was first licensed, regulators were not required to consider ecological impacts in decision making and the primary concerns were power generation and safety.

In the wake of the 1986 amendment to the Federal Power Act, which directed FERC to consider environmental impacts, advocacy groups, such as the Kennebec Coalition and the Natural Resources Council, began efforts to pressure FERC to deny the Edwards Dam Company a new license to operate the dam once its existing license expired in 1993. They demanded

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[51] Maine State Planning Office, "Edwards Dam Removal Update" (Augusta, July 25, 2008), https://web.archive.org/web/20080725131508/http://www.maine.gov/spo/specialprojects/docs/edwsdam_theriverrunsfree.pdf.

[52] Carolyn Jean Hall, Adrian Jordaan, and Michael G. Frisk, "The Historic Influence of Dams on Diadromous Fish Habitat with a Focus on River Herring and Hydrologic Longitudinal Connectivity," 103.

studies regarding environmental impacts and pushed for FERC to deny the license because the dam completely blocked upstream fish passage, despite multiple attempts with fish ladders (limited runs were sustained through a trap and truck program), while only generating 3.5 MW for the state grid, less than a tenth of one percent of the total grid capacity.[53] This proved to be a very important trade-off when considering the relicensing; the benefits associated with many different species having free passage were deemed greater than the minimal contribution to the state's grid. In addition to the small contribution to the grid, the Edwards Dam Company was selling the electricity generated from the dam for three times the average rate at the time, due to an agreement made during the Oil Crisis in the 1970s, and the company only employed four people.[54] The Edwards Dam was the first dam in the country to be denied relicensing by FERC over an issue centered on lack of access for anadromous fish.[55] While the final decision did result in a denial of license from FERC, the process relied on the support of the state as described in its comprehensive river management plan and sustained opposition from environmental advocacy groups to overcome the status quo. The need for sustained advocacy illuminates the major shortcoming of the FERC process: it is not currently set up to make transparent, predictable decisions; policy changes to improve the process will be discussed in the recommendation section of this paper.

The Edwards dam was removed in 1999 and was the first major dam removal project in the United States over concerns regarding anadromous fish passage; it opened up habitat to river herring that had been inaccessible for more than a century. While it was assumed that dam

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[53] Jeff Crane, "'Setting the River Free': The Removal of the Edwards Dam and the Restoration of the Kennebec River," *Water Hist.* 1 (December 1, 2009): 138, https://doi.org/10.1007/s12685-009-0007-2.
[54] Blaine Harden, "U.S. Orders Dam Destroyed; for the First Time, Fish Habitat Takes Priority over a Hydroelectric Dam," *Washington Post*, November 26, 1997.
[55] "FERC Orders Removal of Edwards Dam in US," *Water Power Magazine*, January 12, 1998.

removal would result in the resumption of river herring spawning runs, the proof came more quickly than many expected. In the years immediately following the removal of the Edwards Dam over two million river herring passed upstream of the former location of the dam and accessed historic spawning sites previously accessible only through stocking programs.[56] The immediate return of river herring and other anadromous fish to eighteen miles of the Kennebec River upstream of the Edwards Dam was the first positive sign that removal not only works to restore access but results in far higher abundance than fish ladders or stocking programs. The success of the Edwards dam removal led to the removal of the Fort Halifax dam in 2008, upstream of the former Edwards Dam, which facilitated anadromous fish access to the Sebasticook River, a major tributary of the Kennebec.

Figure 2.

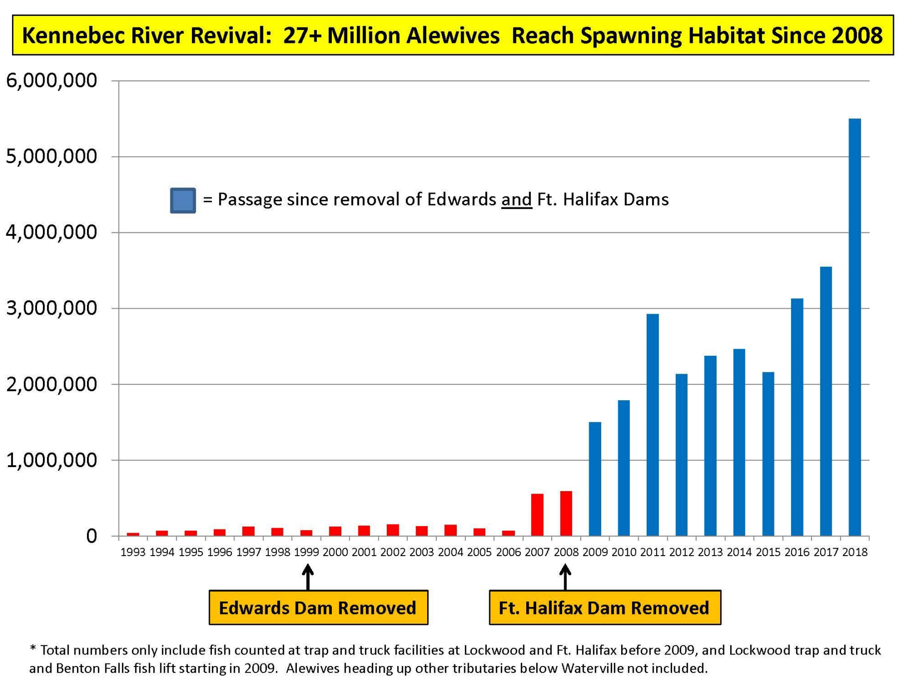

Figure 2. *Alewife passage data from 1993 to 2018 showing the effects of the Edwards Dam removal and the Fort Halifax Dam Removal. Figure used with permission from the Natural Resources Council of Maine.* https://www.nrcm.org/programs/waters/restoring-alewives-maine-rivers/

[56] Crane, "'Setting the River Free,'" 145.

The Fort Halifax Dam was removed after its owner, FPL Energy Maine Hydro, upheld an agreement from 2003 which required either the installation of a fish ladder or the removal of the dam.[57] After the ladder was deemed too expensive compared to the potential generation profits from the dam, the company initiated removal proceedings and successfully defeated legal efforts to fight the removal from residents on the shore of the impoundment above the dam. **Figure 2** shows the dramatic increase in alewife passage on the Kennebec and Sebasticook Rivers starting slowly after the Edwards Dam removal and increasing substantially in the wake of the Fort Halifax Dam removal.[58] The passage numbers before and after the removals show the effectiveness of dam removal for fish migration upstream and the resulting rebound of populations of anadromous fish. Given the life histories of anadromous fish, the results of these dam removals raise the question of whether or not ecological impacts beyond the Kennebec itself, in the coastal waters of the Gulf of Maine, ought to be considered in the FERC process.

Significant fish passage improvements were also made on the Penobscot River in the past two decades. The Penobscot River Restoration Project, completed in 2016 after more than a decade of negotiations among the Penobscot Nation, environmental nonprofits, dam owners, and community stakeholders resulted in the removal of two dams and the creation of a nature-like fishway on a third. The project involved establishing the Penobscot River Restoration Trust to purchase three key dams: the Great Works Dam, the Veazie Dam, and the Howland Dam. The Trust worked with dam owning companies to purchase the three dams prior to removals and negotiated with community stakeholders to reach a final consensus. The project involved several trade-offs: in exchange for supporting the project, the dams' owners were granted increases in

[57] Peter Foote and John Hart, "Session C1- The Anatomy of a Dam Removal- Ft. Halifax Project, Maine," n.d., 41.
[58] Natural Resources Council of Maine, "Restoring Alewives in Maine Rivers" (NRCM, n.d.), https://www.nrcm.org/programs/waters/restoring-alewives-maine-rivers/.

generation allowances on their licenses at six upstream dams which resulted in a net increase in generation.[59] The City of Howland negotiated the construction of a nature-like fishway around the dam to preserve the existing impoundment created by the dam, but agreed that if, in ten years, the fishway has not achieved the same results for river herring and other anadromous species as dam removal would have, then the dam will be removed. The negotiations over the installation of the nature-like fishway are a good example of creative negotiations that can occur when the importance of ecological considerations is factored into the decision making process. The project opened access to more than 2,000 miles of river and tributaries to anadromous fish. By prioritizing access for anadromous fish through strategic removal, the Penobscot River Restoration Trust was able to substantially increase access for fish while expanding power generation in the river system. This project demonstrates that both developmental and non-developmental concerns can be accommodated while prioritizing removal of dams with low generating capacity and high habitat obstruction.

As was the case on the Kennebec and Sebasticook rivers, the removals on the Penobscot River also immediately elevated upstream migration. Pre-removal, the Penobscot saw runs of fewer than a thousand river herring and even lower numbers of American shad and Atlantic salmon.[60] In 2018, 2019, and 2020, the Penobscot River experienced river herring runs of about 2 million fish and 2021 resulted in a run of about 1.7 million fish according to data from the Maine Department of Marine Resources.[61] These passage numbers are an encouraging sign that

[59] Natural Resources Council of Maine, "Penobscot River Restoration Project" (NCRM, n.d.), https://www.nrcm.org/programs/waters/penobscot-river-restoration-project/.
[60] Joshua Royte, "Penobscot River Restoration Project, Maine, USA Early Results and Hydro-Balancing Efforts" (The Nature Conservancy, n.d.), https://damremoval.eu/wp-content/uploads/2016/11/4_Dam-Removal-Europe-Penobscot-River-dam-removals-Josh-Royte.pdf.
[61] Pete Warner, "Penobscot River Is on Track to See Fewest Atlantic Salmon in Recent Years," *Bangor Daily News*, August 29, 2021, https://bangordailynews.com/2021/08/29/outdoors/penobscot-river-is-on-track-to-see-fewest-atlantic-salmon-in-recent-years/.

native species are returning to their historic spawning grounds, as was experienced on the Kennebec and Sebasticook rivers. These responses to dam removal are encouraging for anadromous fish species; they suggest that recovery in other river systems is attainable. While it is beneficial to restore these species for their own sake, their recovery becomes even more important when their impact on related ecosystems is considered. Emerging research shows the benefits of restoring connections between related ecosystems, such as coastal waters and rivers.

Ecosystem Connectivity and Ecological Function

Ecosystem connectivity is the natural flow of energy, nutrients, and carbon through and between ecosystems and is particularly important for anadromous fish that require access to both marine and freshwater ecosystems to complete their lifecycle. As anadromous fish, river herring provide an important connection between marine and freshwater ecosystems. They spend most of their lives in marine ecosystems but also a critical portion in freshwater ecosystems during yearly spawning runs. River herring are an important source of food for predators in the Gulf of Maine such as cod and other groundfish while also serving as a part of the nutrient cycle by transporting nutrients (carbon and nitrogen) upstream, benefitting freshwater ecosystems.

Figure 3. Gulf of Maine Food Web

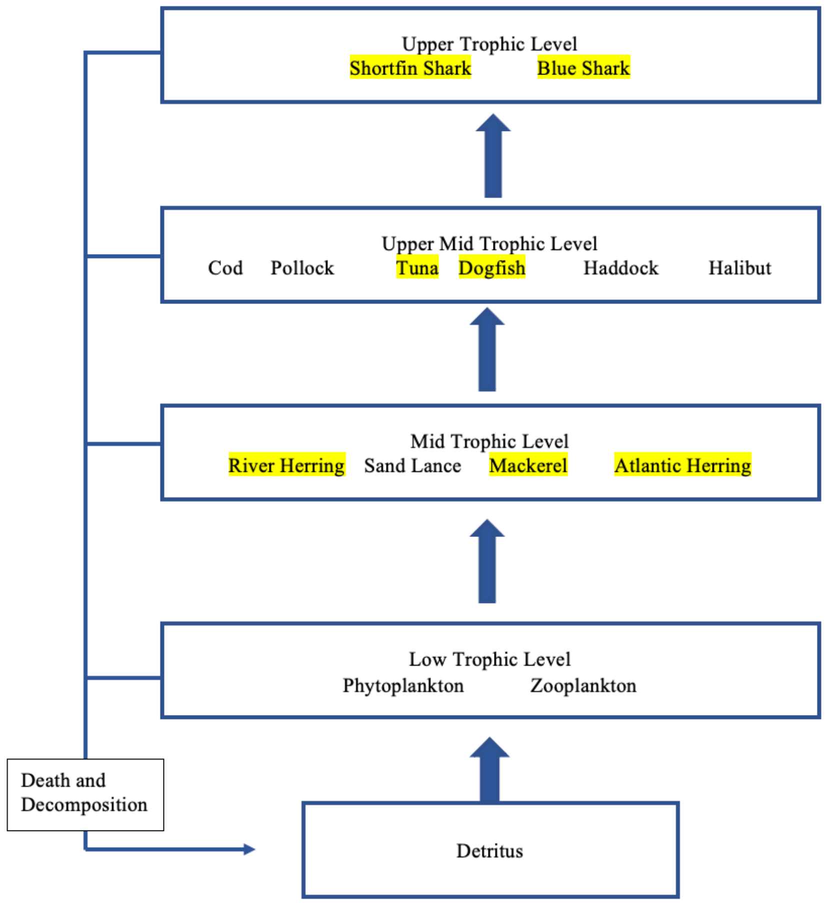

Figure 3. *Simplified Gulf of Maine food web to illustrate the connections between trophic levels and the need to consider the connections when making management decisions. This figure does not show the specific connections between species and the relative levels of abundance. Species that occupy the Gulf of Maine seasonally are highlighted.*

Groundfish spawning areas appear to have evolved to place young of the year groundfish near the mouths of rivers where juvenile river herring migrating downstream to estuarine and marine waters are a ready source of food.[62] Changes in ecosystem connectivity, such as dam construction, can have a wide range of impacts; dams effectively end upstream migration to

[62] Ames and Lichter, "Gadids and Alewives," 76.

spawning habitats for anadromous fish populations.[63] By severing the connection between freshwater and marine ecosystems, dams cause ecosystems to suffer from losses in forage and productivity on multiple levels of the food web.[64] Technological solutions such as fishways and pond stocking compensate to some degree for loss of connectivity but require ongoing upkeep and are expensive programs. The immediate response of anadromous species to the removals on the Kennebec and Penobscot rivers demonstrates the shortcomings of fish passage technologies that were in place prior to dam removals.

While evidence of the connection between cod and river herring is preliminary, it indicates that the loss of an important source of forage may be a factor in the decline of cod populations, in addition to the targeting of spawning aggregations and overfishing more generally. River herring are an important food source for young of the year cod and for older juveniles that rely on lipid-rich river herring to reach sexual maturity.[65] Recent stomach content analyses of cod from Midcoast Maine (with higher abundance of river herring) and Passamaquoddy Bay (with low abundance of river herring) found that groundfish in the Midcoast sites exhibited a "strong seasonal pattern" of river herring consumption whereas the results from Passamoqouddy Bay indicated an invertebrate-heavy diet.[66] The finding of seasonal consumption of river herring in bays near the mouths of large rivers corroborates Ames' and Lichter's work that correlated groundfish spawning grounds with the mouths of large rivers

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[63] Steven Mattocks, Carolyn J. Hall, and Adrian Jordaan, "Damming, Lost Connectivity, and the Historical Role of Anadromous Fish in Freshwater Ecosystem Dynamics," *BioScience* 67, no. 8 (August 2017): 724–25, https://doi.org/10.1093/biosci/bix069.

[64] Beatriz S. Dias, Michael G. Frisk, and Adrian Jordaan, "Opening the Tap: Increased Riverine Connectivity Strengthens Marine Food Web Pathways," ed. Brian R. MacKenzie, *PLOS ONE* 14, no. 5 (May 23, 2019): 1–3, https://doi.org/10.1371/journal.pone.0217008.

[65] Theodore V. Willis, Karen A. Wilson, and Beverly J. Johnson, "Diets and Stable Isotope Derived Food Web Structure of Fishes from the Inshore Gulf of Maine," *Estuaries and Coasts* 40, no. 3 (May 2017): 899–900, https://doi.org/10.1007/s12237-016-0187-9.

[66] Willis, Wilson, and Johnson, 889.

during the downstream migration of juvenile river herring. It also suggests that river restoration efforts through dam removal (on the Kennebec River) may be beginning to stimulate a response in groundfish populations. However, populations of river herring and groundfish are so low that signs of recovery are unclear at best.

Fortunately, there is research from Canada that supports the hypothesis that groundfish will respond to increases in forage even after a collapse. The Northern cod fishery, off the coast of Newfoundland and Labrador, experienced a similar collapse to that in the Gulf of Maine after periods of heavy fishing pressure in the 1960s and the 1980s.[67] The major decline, however, occurred in the early 1990s after colder waters resulted in a massive decline in capelin (*Mallotus villosus*), an important prey species for cod that is very similar in size to river herring and that plays a similar role in the food web.[68] The implication of this research is that cod are unlikely to recover without recovery of the forage base. This theory is supported by an investigation of Northern cod fishery which found strong correlations between increases in capelin biomass and subsequent increases in cod biomass.[69] In this case, the decline of forage food was caused by a cold wave event, not sustained damming of river systems and when the capelin recovered, cod populations began to follow. This indicates that a more complete recovery of river herring in Maine will likely help groundfish populations. While this increase in forage will likely help groundfish populations, it may not be sufficient to enable a full recovery due to other important factors. These include warming waters due to climate change and shifts in the ecosystem dynamics in the wake of groundfish population collapse.

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[67] George A. Rose and Sherrylynn Rowe, "Northern Cod Comeback," *Canadian Journal of Fisheries and Aquatic Sciences* 72, no. 12 (December 2015): 1788, https://doi.org/10.1139/cjfas-2015-0346.
[68] V.S. Bakanev, "Results From Acoustic Capelin Surveys in Div. 3LNO and 2J+3KL in 1991" (Polar Research Institute of Marine Fisheries and Oceanography, March 1992), https://archive.nafo.int/open/sc/1992/scr-92-001.pdf.
[69] Rose and Rowe, "Northern Cod Comeback," 1794.

Research on the role of connectivity among related freshwater and marine ecosystems is expanding as barriers to connectivity are being removed. The signs of recovery for anadromous fish species in the wake of recent restoration projects are inspiring researchers to investigate the potential impacts of river herring restoration on coastal food webs as well as commercially and culturally important species of groundfish including cod and haddock.[70] This field of research was difficult, if not impossible, prior to major removals such as the Edwards Dam and the Fort Halifax Dam because river herring populations were too low to support any meaningful research.[71] Further research on the connection between river herring and cod is necessary to better understand the connection but may be dependent on additional improvements in fish passage as river herring populations are still well below historic levels. Historically low cod populations also hinder research.

Case Studies and Analysis

This section utilizes the SES framework to analyze two case studies of potential future removals in Maine, on the Kennebec and Union Rivers. These analyses highlight the importance of considering related ecosystems when making river management decisions. The SES framework was designed by Elinor Ostrom and is comprised of four main components: Resource Units (RU), Resource System (RS), Governance System (GS), and Users (U). The framework focuses on how the four main categories interact to create outcomes and includes the influence of Social, economic, and political settings (S) as well as Related ecosystems (ECO). It is designed to model the ways in which ecological and anthropogenic factors influence one another to lead to

[70] Karen Wilson, Interview with Karen Wilson, University of Southern Maine, interview by Matthew Thomas, Zoom, February 1, 2022.
[71] Karen Wilson.

outcomes and how changes in one part of the system may impact other components. The diagram below shows the framework as conceived by Ostrom.[72]

Figure 4. Social–Ecological Systems Framework

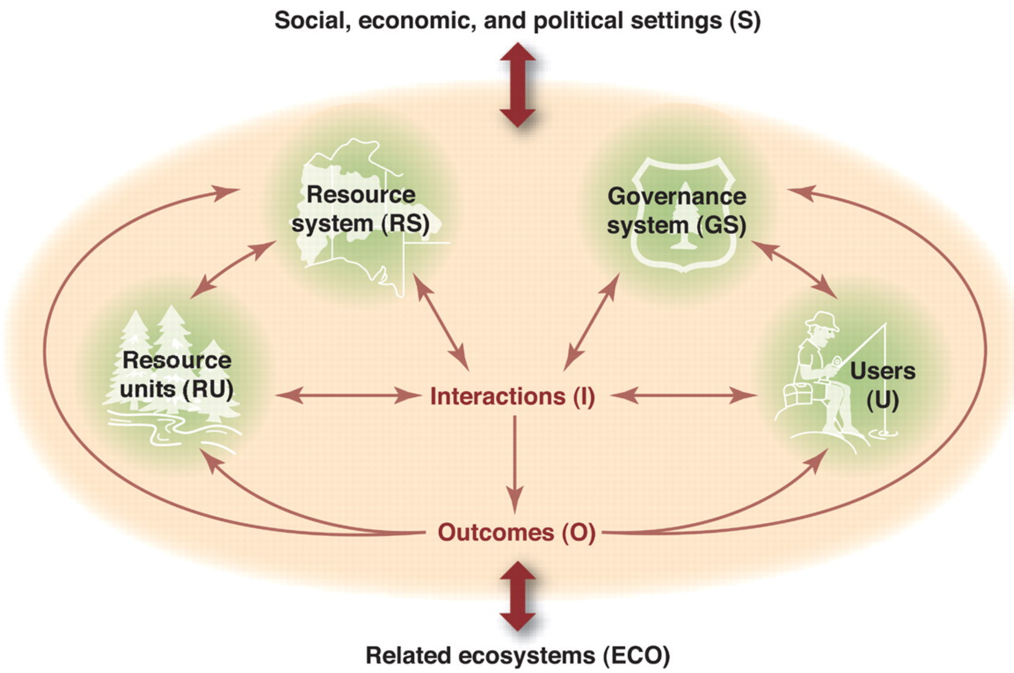
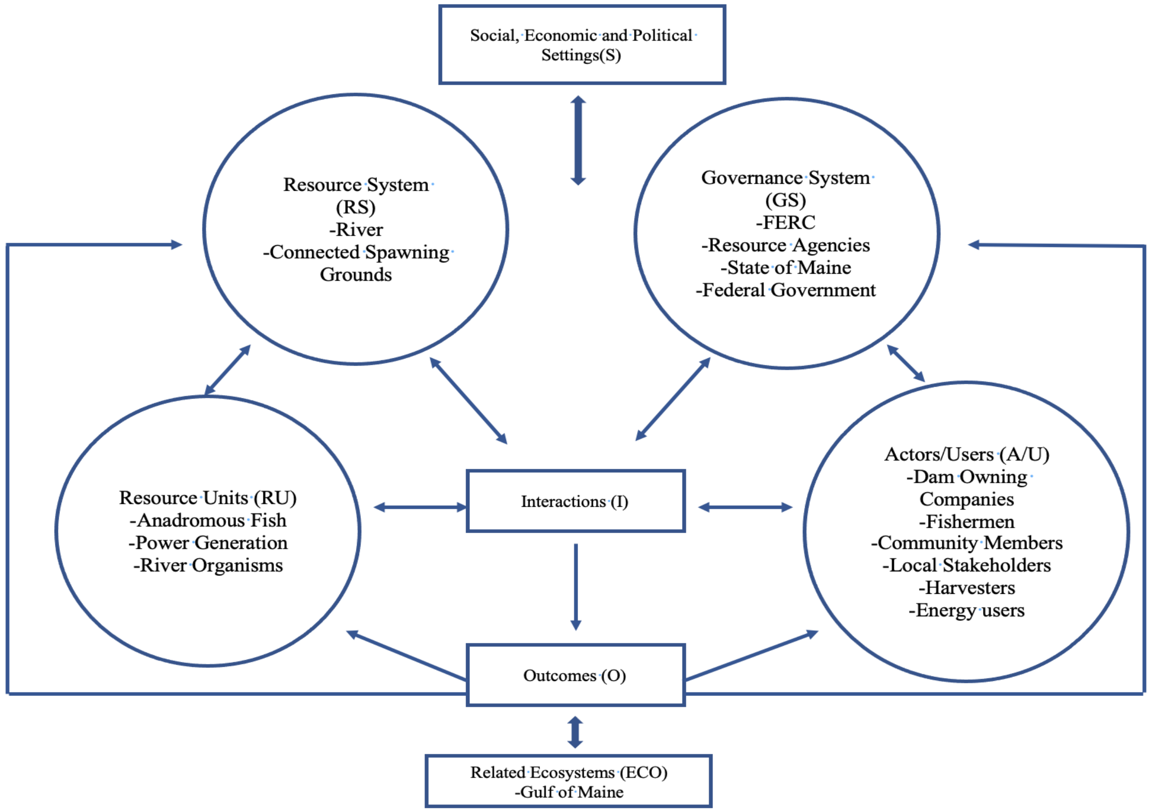


Figure 4. Image used with permission from The American Association for the Advancement of Science through the Copyright Clearance Center

[72] Elinor Ostrom, "A General Framework for Analyzing Sustainability of Social-Ecological Systems," *American Association for the Advancement of Science* 325 (July 24, 2009): 419–22.

Figure 5. Social-Ecological System for Maine Rivers



The FERC process and the SES Framework are strikingly similar, which makes the SES Framework a useful tool to analyze hydropower decision making. The role of FERC in regulating hydropower is to evaluate the many factors involved in dam licensing and to "strike an appropriate balance among the many competing developmental and non-developmental (including environmental) interests… [and statutes such as] NEPA, the Clean Water Act, the Coastal Zone Management Act, the Endangered Species Act, the Fish and Wildlife Coordination Act, and the National Historic Preservation Act."[73] The SES Framework is designed to evaluate the complex interaction of both anthropogenic and environmental factors in social-ecological systems. When thinking about how all of the various factors interact, it is important to realize

[73] Federal Energy Regulatory Committee, "Commission's Responsibilities, Hydropower," n.d., https://www.ferc.gov/industries-data/hydropower.

that decisions, specifically policy decisions, are not isolated in the system and have impacts on all aspects of the complex SES.[74] The governance component of the SES framework is important because it reveals the priorities of the governing system which, in turn, impacts other components in varying ways. The interactions to outcomes component of the SES framework shows how the governance component can impact every other piece of the framework. Policy decisions impact both the ecological and social sides of complex systems and have rippling effects throughout the system.[75] The layering effects of policy decisions over time and inevitable shifts in direction due to political change make the impact of policy decisions even more difficult to predict.

Elinor Ostrom and Michael McGinnis' updated SES framework provides a platform to analyze the trade-offs associated with dam licensing and relicensing and, importantly, contains a section dedicated to considering effects on related ecosystems.[76] Ostrom and McGinnis' update of the SES framework is a slight modification of the original to make it more applicable in a broader range of scenarios. The updated framework has an "Actors" category instead of "Users" to allow for the inclusion of a broader range of individuals and groups that may not be direct users. For example, environmental advocacy groups may not directly use the river but are influential actors in the SES for the river ecosystem. A breakdown of second tier variables (**Table 4**) is used to identify the most relevant issues for regulatory decision making which are then applied to case studies on the Kennebec River and the Union River.

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[74] Ratri Werdiningtyas, Yongping Wei, and Andrew W. Western, "Understanding Policy Instruments as Rules of Interaction in Social-Ecological System Frameworks," *Geography and Sustainability* 1, no. 4 (December 2020): 296, https://doi.org/10.1016/j.geosus.2020.11.004.
[75] Werdiningtyas, Wei, and Western, 296.
[76] Michael D. McGinnis and Elinor Ostrom, "Social-Ecological System Framework: Initial Changes and Continuing Challenges," *Ecology and Society* 19, no. 2 (2014), https://www.jstor.org/stable/26269580.

The framework is broken down the seven first tier variables into fifty-six second tier variables; this allows the framework to be easily adapted to a wide range of common pool resource issues.[77] Fourteen of the second tier variables are relevant to the generation of hydroelectricity and the FERC decision making process and are prioritized in this analysis.

Table 4. Second Tier Variables of the SES Framework

Social, economic, and political settings (S)	S1- Economic Development S4- Other governance systems S7- Technology
Resource Systems (RS)	RS4- Human-constructed facilities RS5- Productivity of system
Governance Systems (GS)	GS8- Monitoring and sanctioning rules
Resource Units (RU)	RU4- Economic value RU7- Spatial and temporal distribution
Actors (A)	A1- Number of relevant actors A8- Importance of resource A9- Technologies available
Action situations: Interactions (I) to Outcomes (O)	I4- Conflicts O3- Externalities to other SESs
Related Ecosystems (ECO)	ECO3- Flows into and out of focal SES

By using key SES tier two variables (**Table 4**), it is possible to apply the findings from the previous removal case study to the evaluation of the impacts of four dams on the Kennebec River and two dams on the Union River.

[77] María del Mar Delgado-Serrano and Pablo Ramos, "Making Ostrom's Framework Applicable to Characterise Social Ecological Systems at the Local Level," *International Journal of the Commons* 9, no. 2 (September 18, 2015): 808, https://doi.org/10.18352/ijc.567.

Kennebec River

The Kennebec River is undergoing a major dam removal effort, led by the State of Maine and conservation groups. The goal is to restore anadromous fish access to the Sandy River, north of Skowhegan. Atlantic salmon are a major driver of this effort due to their status as an endangered species. The Endangered Species Act is a powerful tool to achieve ecological goals because it contains strong requirements for the protection of endangered species regardless of other interests such as power generation that the FPA must address. Environmental advocacy groups worked to have river herring declared as an endangered species, but efforts failed. This restoration effort is primarily driven by Atlantic salmon but all anadromous species, including river herring, stand to benefit from removals. The State of Maine's Kennebec River Resource Management Plan was amended in 2020, adding a section specifically addressing anadromous species. The amendment to the plan explicitly states that dam removal is the best option for restoring anadromous species and notes that power generation at the four dams is limited. The focus is on the Shawmut Dam in Fairfield, the Hydro Kennebec and Lockwood dams in Waterville, and the Weston Dam in Skowhegan; removals will provide passage for anadromous species all the way from the sea to Skowhegan and beyond. When relicensing was initiated for the Shawmut dam, conservation groups successfully made the case that FERC was obligated to undertake an environmental impact study of the cumulative impact of all four dams on Atlantic salmon and other anadromous fish; the study is expected to be completed in 2022.[78] The review will focus on the cumulative impacts of the four dams on fish passage to the Sandy River, the only unimpeded tributary of the Kennebec River. Opening access to the Sandy River will vastly

[78] Collin Woodward, "Federal Regulators Will Review Effects of 4 Lower Kennebec Dams on Fish," *Press Herald* (blog), November 24, 2021, https://www.pressherald.com/2021/11/24/federal-regulators-to-review-effects-of-4-lower-kennebec-dams-on-fish-a-victory-for-conservationists/.

increase the available spawning habitat for anadromous species. It is important to consider these dams collectively because inadequate passage at one dam limits the benefits of dam removal or fish passage infrastructure at the remaining dam sites.

The ecological side of the SES Framework considers the relationship between Resource Systems and Resource Units, in this case focusing on the Kennebec River Watershed. The Resource Unit's primary second-tier variables are RU4- Economic Value and RU7- Spatial and Temporal Distribution. The economic value of the river watershed, according to the Kennebec River Resource Management Plan is primarily based on recreational fisheries for striped bass and American shad, commercial fisheries for river herring and American eel, as well as the former Atlantic salmon fishery closed due to the listing of Atlantic salmon as an endangered species in 2000.[79] The river management plan reveals that "the striped bass fishery supported 3,110 jobs and generated $202-million dollars in revenue in 2016… The lucrative American eel (elver) fishery was worth over $20 million dollars in 2018 and 2019."[80] It also explores the potential value of the blocked Atlantic salmon habitat and places it at $10.4 million dollars for the habitat affected by the four dams.[81] These estimates are based on the current state of the river, as dammed, so the value of the potential fisheries will likely increase if the river's flow is returned to a more natural state. The four dams in question have generation capacities totaling 6.4% of Maine's total hydroelectric generation which is 0.43% of Maine's total energy generations.[82] This is a total of 47.08MW of generation capacity and a yearly production of 273,135.931MWh; the power is sold to ISO-New England, a regional, independent service

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[79] Maine Department of Marine Resources, "Kennebec River Resource Management Plan, Diadromous Resources Amendment" (Augusta, December 2020), https://www.maine.gov/dmr/laws-regulations/documents/Final%20Amendment_12_22.pdf.
[80] Maine Department of Marine Resources, 29.
[81] Maine Department of Marine Resources, 29.
[82] Maine Department of Marine Resources, 28.

operator for distribution of energy at an average wholesale price of $42.15 per MWh, making the gross value of generation across all four dams $11,512,133.20.[83,84,85] The value of power generation and fisheries are the primary economic components of RU4. Moving to RU7, spatial and temporal boundaries, the consideration shifts to the ecosystem context of the resource units within the larger system. The dams are located between Waterville and Skowhegan, Maine which is a critical stretch of the Kennebec River. Removal would allow for access by anadromous species to the Sandy River and other historic spawning grounds upriver of Waterville. The location of these dams is important because of the amount of spawning habitat blocked by their presence: the State of Maine estimates that 59.6% of spawning habitat for blueback herring is above the Lockwood dam.[86] These considerations are the most important in the RU7 section of the framework and are directly linked to the RS5 section.

The Resource System component of the framework addresses the characteristics of the entire Kennebec River Watershed with the most important variables being RS4- Human Constructed Facilities and RS5- Productivity of the System. The Human Constructed Facilities component is relatively straightforward: there are four dams in question that are relevant to this analysis: the Shawmut, Hydro Kennebec, Lockwood, and Weston Dams. The other component of human constructed facilities is the fish passage infrastructure installed on the dams to facilitate upstream access, with the goal of offsetting the impact of the dams on connectivity. The fish passage infrastructure component of RS4 is connected to RS5- Productivity of the System.

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[83] Federal Energy Regulatory Committee, "FERC Active Licenses," Spreadsheet, n.d.
[84] MW to MWh conversion from "Maine Hydropower Study" prepared for Maine Governor's Energy Office, Augusta, Maine by Kleinschmidt, February 2015, https://www.maine.gov/energy/sites/maine.gov.energy/files/inline-files/001-ME-GEO-Rpt-02-04-15.pdf.
[85] ISO New England, "New England's Wholesale Electricity Prices Up in 2018," n.d., https://www.iso-ne.com/static-assets/documents/2019/03/20190312_pr_2018-price-release.pdf.
[86] Maine Department of Marine Resources, "Kennebec River Resource Management Plan, Diadromous Resources Amendment," 21.

When considering the productivity of the system, it is important to note the cumulative ecological impact of the four dams. In order to provide for successful restoration, a fish passage efficiency of at least 90% passage is required at individual dams.[87] Focusing on RS5 directly, system productivity is a measure of the total production of biological material in a given time span. In relicensing, the current productivity of anadromous fish is compared to potential productivity if the dams are removed. The social side of the SES framework considers the impacts of Actors and Governance Systems on the entire SES. The Actors category focuses on relevant parties in the system, their connection to the resources, and technologies available to said actors. Within the Kennebec River Watershed, the most active participants in relicensing are the companies that own the dams (Brookfield Renewables, Merimil Limited Partnership, and Hydro Kennebec LLC), river herring harvesters, fishermen in the Gulf of Maine, environmental advocacy groups (Conservation Law Foundation, Kennebec Coalition), the State of Maine (through its Kennebec River Comprehensive Management Plan as amended), and community stakeholders. Community stakeholders, such as property owners and business operators, often participate in the proceedings; FERC may or may not consider their interests. The subcategory A8- Importance of Resource allows analysis of hydropower in relation to improvements in solar and wind technology that diversify the feasible options for renewable power sources and has a bearing on the importance of the resource to the various actors.[88,89] With wind and solar power projected to increase quickly throughout the United States, and in Maine specifically, the State of Maine will be less reliant on hydropower for renewable energy generation. Diadromous fish

[87] Noonan, Grant, and Jackson, “A Quantitative Assessment of Fish Passage Efficiency,” 456.
[88] U.S. Energy Information Administration, “Solar Generation Was 3% of U.S. Electricity in 2020, but We Project It Will Be 20% by 2050.”
[89] U.S. Energy Information Administration, “Wind Explained, Electricity Generation from Wind” (U.S. Department of Energy, March 17, 2021), https://www.eia.gov/energyexplained/wind/electricity-generation-from-wind.php.

provide recreational and commercial value to actors through harvesting and fishing practices and contribute to ecosystem resilience in the food web of marine ecosystems as well. The final important variable to consider is A9- Technologies Available within the Kennebec River system; this focuses on fish passage technology and alternative energy sources (the latter discussed above). Fish passage technology, where feasible, is often proposed as a compromise that justifies the relicensing of hydroelectric dams. However, research and monitoring of existing passage infrastructure show an average passage success rate of 41.7% on average for each dam, far below the ideal passage rate of 90-100%.[90] This average is also skewed by the fact that some species have higher rates of passage than others. The discrepancy between the average passage rate and the ideal rate indicates that fish passage infrastructure is unlikely to provide safe passage for the majority of fish, even if a few species are able to pass effectively. This poor performance is magnified when considering the four dams in question given the cumulative impact of inefficient passage across all four dams: even if fish passage infrastructure is successful at one dam, the effort required to pass all four will likely result in suboptimal passage rates across the entire system. When the Shawmut Dam came up for relicensing and resource agencies (Maine DMR and the National Marine Fisheries Service (NMFS)) pushed for the removal of the dams in the interest of anadromous fish populations, FERC recognized the importance of considering cumulative impact by conducting an Environmental Impact Statement addressing all four dams.[91,92] The range of actors involved in this issue and the importance to them of various resources requires that decision making address trade-offs among the various interests. FERC

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[90] Noonan, Grant, and Jackson, “A Quantitative Assessment of Fish Passage Efficiency,” 456.
[91] Natural Resources Council of Maine, “Kennebec River Dam Removal: It Is TIme to Free the Kennebec Above Waterville,” 2021, https://www.nrcm.org/wp-content/uploads/2021/02/Kennebecbriefingpaper.pdf.
[92] National Marine Fisheries Service, “COMMENTS, RECOMMENDATIONS, PRELIMINARY TERMS AND CONDITIONS, and PRELIMINARY FISHWAY PRESCRIPTIONS for the Shawmut Hydroelectric Project (FERC No. 2322)” (NOAA, August 28, 2020).

must account for the public interest in generating power for the grid, the impacts of dams on the immediate ecosystem, and the impacts on related ecosystems.

The Governance section of the SES Framework sheds light on how decisions are made and how trade-offs might be assessed. It focuses on the different governing bodies of the system, their interaction, and their influence on other components of the system. The primary governing body in this analysis is FERC. Other important governing bodies are the State of Maine and the National Marine Fisheries Service.

The FERC process, as updated after the passage of the ECPA, must give "equal consideration" to developmental and non-developmental components such as the hydroelectric potential, the benefits to interstate commerce, the protection of fish and wildlife, and other beneficial public uses. There are four important relevant components of the ECPA within the FPA: section 4(e) establishes the "equal consideration" standard, section 10(a) directs FERC to consider resource agency comments to ensure the project balances developmental and non-developmental components, section 10(j) requires FERC to consider resource agency comments under the Fish and Wildlife Coordination Act pursuant to fish and wildlife resources, and section 18 authorizes resource agencies to set requirements for fish passage infrastructure.[93]

[93] U.S. Fish and Wildlife Service, "Overview of the Federal Power Act and the Hydropower Relicensing Process," n.d., https://www.fws.gov/policy/hydrochap2.pdf.

Table 5. ECPA Amendments to the FPA

Section 4(e)	"In deciding whether to issue any license under this Part for any project, the Commission, in addition to the power and development purposes for which licenses are issued, shall give equal consideration to the purposes of energy conservation, the protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality [emphasis added]."[94]
Section 10(a)	FERC shall ensure that plans are "best adapted to a comprehensive plan for improving or developing a waterway or waterways for the use or benefit of inter- state or foreign commerce, for the improvement and utilization of waterpower development, for the adequate protection, mitigation, and enhancement of fish and wildlife (including related spawning grounds and habitat), and for other beneficial public uses, including irrigation, flood control, water supply, and recreational and other purposes referred to in section 4(e)"[95]
Section 10(j)	That in order to adequately and equitably protect, mitigate damages to, and enhance, fish and wildlife (including related spawning grounds and habitat) affected by the development, operation and management of the project, each license issued under this Part shall include conditions for protection, mitigation, and enhancement. ...[S]uch conditions shall be based on recommendations received pursuant to the Fish and Wildlife Coordination Act (16 U.S.C. 661 et seq.) from the National Marine Fisheries Service, the United States Fish and Wildlife Service, and State fish and wildlife agencies.[96]
Section 18	[FERC] shall require the construction, maintenance, and operation by a licensee at its own expense of such ... fishways as may be prescribed by the Secretary of the Interior or the Secretary of Commerce, as appropriate.[97]

These provisions are central to the balancing of trade-offs when making decisions about the river system such as the contribution to the state grid and the importance of anadromous fish passage. The Kennebec River Resource Plan articulates the State of Maine's policies for river management, specifically anadromous fish, and is to be considered under sections 10(a) and

[94] U.S. Congress, United States Code: Federal Power Act.
[95] U.S. Congress.
[96] U.S. Congress.
[97] U.S. Congress.

10(j) of the FPA. The Plan recognizes the cumulative impact of the four dams on fish passage and establishes as state policy that "dam removal is the most effective fish passage strategy and reduces the cumulative impacts of multiple projects. When the need to meet energy objectives makes dam removal infeasible or undesirable, high standards of passage efficiency at upstream and downstream fishways and proper management of operations to facilitate fish passage are required."[98] The Plan calls for prioritizing anadromous fish restoration and notes the immediate impact of prior dam removals on river herring, projecting that the removal of the four dams would result in river herring access to an additional 59.6% of historic spawning habitat, potentially increasing production of blueback herring by two million fish per year with additional alewife production as well.[99] Federal resource agencies have listed river herring as species of concern and prioritized restoration of populations.[100,101] Going forward, the FERC process considers how to balance the articulated interests of all involved groups under relevant laws while following the existing governance under the FPA requiring consideration of resource agency comments and the goals outlined in the Kennebec River Resource Plan.

Moving beyond the four main components of the SES framework, there are two important sections of the framework that consider issues related to, but separate from, the immediate system. These two components of the SES framework are Social, Economic, and Political Settings as well as Related Ecosystems. The Social, Economic, and Political Settings section considers the impact of external factors on the four components of the SES framework. The important variables within the section are S1- Economic Development, S4- Other

[98] Maine Department of Marine Resources, "Kennebec River Resource Management Plan, Diadromous Resources Amendment," 10.
[99] Maine Department of Marine Resources, 21.
[100] NOAA National Marine Fisheries Commission, "River Herring Species of Concern" (NOAA, 2007), https://www.nrc.gov/docs/ML1004/ML100481337.pdf.
[101] ASMFC, "Shad and River Herring Management" (Atlantic States Marine Fisheries Commision, n.d.), http://www.asmfc.org/species/shad-river-herring.

governance systems (discussed in Governance section), and S7- Technology (discussed above in the fish passage technology section). Economic Development is a factor into this case because the dams provide jobs to the local economy and property tax revenue to towns. The Shawmut Dam supports the operation of Sappi's mill in Skowhegan; the company maintains that the mill is dependent on the impoundment created by the Shawmut Dam. The Sappi Paper Mill provides $389,000 in local tax revenue annually while the Lockwood and Hydro Kennebec provide $642,526 in local tax revenue per year (tax revenue could not be found for Shawmut Dam or Weston Dam but is assumed to be similar).[102,103] It is possible that the losses in tax revenue and to the local economy could be at least partially offset through revitalized fishing and other recreational opportunities that come with a free flowing river. The Sappi Paper Mill also provides significant value for the surrounding area and the logging industry as one of the only remaining paper mills in Maine; its closure would result in the loss of hundreds of jobs locally and throughout Maine.[104] The concern is that removing the Shawmut Dam will cause water levels to drop so significantly that the mill will be unable to pull enough water from the river in order to cool infrastructure and operate the mill. However, this claim is not supported by any significant documentation and requires further investigation by the State of Maine.[105] It is worthwhile to note that the State of Maine's stance has changed recently due to opposition from the paper mill's employees and the broader industrial community. The shift is due to concerns about the removal's impact on Sappi's mill operations and pressure from employees and management. This change in support will likely impact the state's recommendations which are

[102] Town of Winslow Town Council, "Special Town Council Meeting, March 23, 2021 Regarding Kennebec River Management Plan," Meeting Agenda, March 23, 2021, https://www.winslow-me.gov/events/view-event.php?id=1735.
[103] Katherine Revello, "Future of Shawmut Dam, Sappi Mill Remain Uncertain" (The Maine Wire, August 25, 2021), https://www.themainewire.com/2021/08/future-of-shawmut-dam-sappis-somerset-mill-remain-uncertain/.
[104] Katherine Revello.
[105] Interview with Sean Mahoney, Conservation Law Foundation, interview by Matthew Thomas, February 1, 2022.

considered by FERC when making decisions.

The last component of the SES Framework to factor into the Interactions to Outcomes section is the impact of related ecosystems on the Kennebec River watershed and vice versa. Within this system, the related ecosystem variable to consider is ECO3-Flows into and out of an SES. This component is important to assessing FERC's analysis because of the provisions in the ECPA (discussed above) that mandate FERC's "equal consideration" of developmental and non-developmental factors, the views of resource agencies, and the state river management plan. The primary part of the related ecosystems component is the predator/prey relationship between river herring and groundfish in the Gulf of Maine. In the past two decades, since the removal of dams on the Kennebec and Penobscot Rivers, available research has pointed towards an ecological connection between river herring and groundfish, suggesting that groundfish are unlikely to return in substantial numbers without the return of river herring.[106] The Past Removals case study focused on assessing the impact dam removal has on anadromous fish populations and looked at specific examples showing how quickly populations return and how much higher they are in the wake of removal compared to the use of fish passage infrastructure. This finding, combined with recent research about the value of connected ecosystems and free flowing rivers, warrants consideration in the FERC relicensing process. The best available evidence in the wake of the removals discussed in the Previous Removals study is that river herring return in high numbers when dams are removed and that all signs point towards a connection between river herring and cod which adds significant weight to the arguments in favor of removal.

The Incomes to Outcomes section of the SES Framework is a useful tool for analyzing

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[106] Jonathan A. Hare et al., "A Review of River Herring Science in Support of Species Conservation and Ecosystem Restoration," *Marine and Coastal Fisheries* 13, no. 6 (December 2021): 627–64, https://doi.org/10.1002/mcf2.10174.

the FERC decision making process because it requires decision makers to account for a variety of factors within the SES. The most important Interaction variable within this section is I4-Conflicts; FERC's role is balancing the trade-offs among the developmental and non-developmental interests: in this case, the benefits of hydroelectric generation from the four dams compared to the ecological impacts. Inevitably this process identifies conflicting interests among the various actors.

An important variable of the Interactions to Outcomes section is O3- Externalities to other SES which considers the impacts of the system on related systems and vice versa. The Kennebec River ecosystem's connection to the Gulf of Maine is an important factor to consider because the evidence connecting river herring and groundfish indicates that any groundfish recovery will rely on increased river herring populations. One benefit of restoring fish populations, both river herring and groundfish, is to revitalize the commercial fisheries associated with both to generate economic benefits for the state. While the connection is yet to be fully understood, all signs point towards river herring being a critical part of groundfish recovery, a recovery which could bring millions of dollars back into Maine's fishing industry. Recent efforts to restore historic anadromous fish populations have seen signs of success in the wake of previous removals and the connection between river herring and groundfish may become clearer should the four dams in question be removed. It is unlikely that fish passage infrastructure will yield the results necessary for any serious recovery of species because the efficiency required to restore species has yet to be demonstrated, especially across multiple dams. Since the dams provide a small portion of the total electricity in the state, it is unclear that fish passage is an appropriate accommodation because it is still unproven at the high standard required for this project.

Union River

The Union River drains a small watershed and runs through Ellsworth, Maine, emptying into Union River Bay near Mt. Desert Island. Two dams, the only two FERC regulated dams on the Union, are currently going through relicensing; the nature of this river and its dams are different from those of the Kennebec making it a useful, comparative case study. It is an important watershed for anadromous fish due the relatively large amount of spawning habitat relative to the size of the watershed. River herring populations are sustained through a trap and truck program. The lower dam, the Ellsworth Dam, is used for hydroelectric generation while the upper dam, Graham Lake Dam, is used for water storage in Graham Lake to facilitate generation downstream at the Ellsworth Dam. The SES Framework is helpful in analyzing the impacts of the dams on the watershed and other non-developmental factors that FERC must consider. For the sake of brevity, and due to many overlapping sections to the Kennebec River case study, similarities will be mentioned but not explored in detail.

The Resource Units category for the Union River has similar components to the Kennebec River Study, although there are fewer dams which simplifies the analysis. The major resource units in the system are anadromous fish, freshwater fish and wildlife, and electricity generation from the dam. For RU4- Economic Value, there are two dams: the Ellsworth Dam and the Graham Lake Dam and of the two dams, only the Ellsworth Dam has fish passage infrastructure (a fish lift) installed. The only generation on the Union River is from the Ellsworth Dam with a generating capacity of 8.9MW and total annual generation of 30,511MWh.[107] This generation is 1.2% of Maine's total hydropower capacity and using the

[107] Brookfield Renewable Energy Group, "Ellsworth Hydroelectric Project FERC No. 2727-086 Application for New License for Major Water Power Project – Existing Dam," FERC Relicensing Application (Maine, December 30, 2015).

same valuation of hydropower from the Kennebec Study, this amount of generation results in gross profits of $1,286,038.65 per year.[108] As for the value of river fisheries, data is not available in the same way it is for the Kennebec River. The dams on the river obstruct passage completely and the only method of passage is through a state-run trap and truck program which severely limits the productivity of anadromous fish populations. Potential economic value is high however, as estimates put potential river herring runs on the river in the millions of individuals and value can be extracted from other harvesting programs and state data.[109] The other consideration in the Resource Unit section is RU7- Spatial and Temporal Distribution. The Union River Watershed contains many different streams, ponds, and lakes that are potential spawning grounds for anadromous fish but the dams on the river are near the mouth which severely limits fish movement in the watershed, effectively blocking fish from the entire system. This is an important consideration in the FERC analysis because the dams not only impede passage but block access to the vast majority of the spawning grounds within the watershed.

The Resource System category of the Union River SES focuses on the variables RS4- Human-Constructed Facilities and RS5- Productivity of System. The Human-Constructed Facilities components for the Union River are the Ellsworth Dam and the Graham Lake Dam. The fish lift installed at the Ellsworth dam severely limits fish productivity and requires trucking above the Graham Lake dam which has no fish passage. The standard for the Union River is a 90% total passage rate, which would require efficiency of about 95% per dam with passage at each dam.[110] The Productivity of System variable of the section is hard to quantify because of

[108] ISO New England, "New England's Wholesale Electricity Prices Up in 2018."
[109] College of the Atlantic, River Ecology and Conservation Class, "Alewife Restoration in the Union River Watershed" (College of the Atlantic, June 2004), http://www.gulfofmaine.org/kb/files/9409/Alewife%20reintroduction%20report.pdf.
[110] FERC, Office of Energy Projects, Division of Hydropower Licensing, "Union River Draft Environmental Assessment for Hydropower License" (Washington D.C., November 2018), https://www.ferc.gov/sites/default/files/2020-06/P-2727-092-DEA.pdf.

the history of obstructions on the river and a lack of records. As stated above, the potential river herring run of the river is estimated to be in the millions; it is currently a fraction of its potential. Moving to the social side of the SES Framework, the Actors category of the system is similar to the Kennebec River system. The variable A1- Number of Relevant Actors for the Union River consists of the State of Maine, Brookfield Renewables (owner of both dams), river herring harvesters, environmental advocacy groups (Downeast Salmon Federation, Natural Resources Council of Maine), and the property owners on Graham Lake. The major difference between the Kennebec River and the Union River systems is that the residents of Graham Lake play a major role in decision making in the Union River Watershed; they believe that the value of their property would drop significantly with the removal of the Graham Lake Dam and subsequent drainage of the lake. As for A8- Importance of resource, the importance of Graham Lake to these property owners is very high and will likely be judged to outweigh the benefits of dam removal; a technological approach to fish passage will be required should the dam remain. Otherwise, this section is the same as the Kennebec River case study: current power generation on the river is low and the obstruction of spawning habitat is drastic. The two resources have the same value on the Union River as they do on the Kennebec River. The A9-Technologies available is also the same: the benefits and limits of fish passage technology development would be similar in both river systems.

The Governance section of the SES Framework for the Union River matches the Kennebec River almost completely except for one key difference. The relicensing process for the Ellsworth Dam is currently unlikely due to the State of Maine's determination that operation of the dam impacts water quality such that it does not meet standards set by the Clean Water and

Federal Water Pollution Control Acts.[111] This certification is required for FERC to authorize the dams' relicensing and as such, the project is stalled.

The Social, Economic, and Political settings side of the SES Framework for the Union River Watershed is mostly centered on the concerns of the residents of Graham Lake regarding water levels. The rest of the category is similar to the Kennebec River study with regard to property tax revenue from the dams, the potential value in the fisheries should passage rates increase, and the goals of the state to restore anadromous fish populations. Any passage infrastructure will need to be highly effective to pass enough fish to support species recovery. This is an important consideration for FERC because there are so many stakeholders who will be affected if Graham Lake is drained; the lake provides substantial value for local tourism and recreation in the summer months while lake front properties bring in significant property taxes.

The Related Ecosystems component for the Union River case study is exactly the same as for the Kennebec River case study. In the wake of the removals of the Edwards Dam, the Fort Halifax Dam, and the Penobscot River Restoration Project, it is clear that dam removal results in elevated fish counts. These counts are far higher than the numbers seen on rivers with fish passage infrastructure and speak to the value of fully connected fresh water and marine ecosystems.

The Interactions to Outcomes section of the SES Framework for the Union River does differ substantially from the Kennebec River case study, primarily because of Graham Lake. For the important variable, I4- Conflicts, the Union River case includes two primary conflicts. First, there is conflict between power generation at the Ellsworth Dam and its significant impact on

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[111] Stephen Rappaport, "DEP Denies Permit Critical to Ellsworth Dam License Renewal," *The Ellsworth American*, March 24, 2020, https://www.ellsworthamerican.com/maine-news/waterfront/dep-denies-permit-critical-to-ellsworth-dam-license-renewal/.

anadromous fish. Under FERC's Equal Consideration mandate, the annual total generation of 30,511MWh must be weighed against the resulting loss of fish productivity. The generation total is 1.2% of the hydropower capacity in the state and 0.41% of the total grid. FERC must consider the benefit provided by the dam in contrast to the interests of resource agencies (NMFS, Maine DMR) in restoring anadromous fish populations in addition to other ecological concerns about the river such as water quality. The Graham Lake dam, while not a generating facility, makes the decision making process more complex because of the concerns of the residents of Graham Lake regarding significant impacts should the dam be removed.

The FERC relicensing process, as currently constructed, has a framework that requires balancing developmental and non-developmental interests; however, there is little guidance on how to achieve this balance. According to the FERC handbook for licensing proceedings, when "balancing developmental and non-developmental objectives, the Commission will consider the *relative value* of the existing power generation, flood control, and other potential developmental objectives in relation to non-developmental objectives such as present and future needs for improved water quality, recreation, fish, wildlife, and other aspects of environmental quality."[112,113] Section 4(e) from the ECPA focuses on the "equal consideration" provision in the FPA; it directs FERC to consider "the purposes of energy conservation, the protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality."[114]

This may result in decisions that don't adequately reflect the latest scientific evidence

[112] Italics added
[113] Federal Energy Regulatory Committee, "Handbook for Hydroelectric Project Licensing and 5 MW Exemptions from Licensing," April 2004, 2–24, https://www.ferc.gov/sites/default/files/2020-04/licensing-handbook.pdf.
[114] Federal Energy Regulatory Committee, A-8.

regarding the ecological impacts of dams. It is difficult to make a decision in this process because it relies on a variety of conflicting interests and uncertainty, especially for ecological factors. Although the ECPA amendments to the FPA can be interpreted in a way that balances developmental and non-developmental interests, the language of the amendments is vague and may result in inconsistent decision making that undervalues ecological concerns. In order to accurately balance developmental and non-developmental factors, the FERC decision making process should reflect current research regarding ecosystem connectivity and the impacts of dams on related ecosystems. Unfortunately, the vague language of the amendments can result in an undervaluation of the ecological significance of river herring and an reliance on the status quo.

Using the case studies of the Kennebec and Union Rivers, this section will illustrate how relicensing decisions could be structured under the current language of the FPA. After reviewing the potential implications of these decisions, there will be recommendations to amend the FPA and structure of resource agency comments to better reflect the best available science and clarify the vague sections to standardize the decision making process.

For the Kennebec River case study, important factors in the balancing process are the generating capacities of the dams, the impact of the generation on the state's grid, the impact of the dams on fish migration, and related habitat. In this case, the four dams contribute a total of 47.08MW of electricity which is 0.43% of Maine's total electricity generation, at an annual gross corporate profit of about $11.5 million dollars for the companies, while blocking a significant portion of historic anadromous fish spawning grounds, including 59.6% of blueback herring spawning grounds.[115] Beyond the Kennebec River watershed, the potential benefits to species in

[115] Maine Department of Marine Resources, "Kennebec River Resource Management Plan, Diadromous Resources Amendment," 21.

the Gulf of Maine that rely on river herring for forage, compared to the small amount of generation provided by the dams, illustrates the impact of the dams on non-developmental factors.

Turning to the Union River case study, a similar situation occurs with regard to the "equal consideration" of developmental and non-developmental assets. The Ellsworth Dam has a generation capacity of 8.9MW and a total yearly generation of 30,511MWh.[116] This generation is 1.2% of Maine's total hydropower capacity, 0.05% of Maine's total electrical grid, and using the same valuation of hydropower from the Kennebec Study, this amount of generation results in gross profits of $1,286,038.65 per year.[117] For anadromous fish, the two dams on the Union River block access to the majority of the watershed's spawning grounds and thus impact the Gulf of Maine ecosystem. In the case of the Union River, the limited generation of the Ellsworth Dam compared to the loss of access to spawning grounds will be an important component of the decision making.

The next section of the FPA that is relevant for balancing developmental and non-developmental factors is section 10(a) which directs FERC to consider comprehensive plans in the decision making process. The language "instructs FERC to solicit comments from resource agencies and Indian tribes (if affected by the project) on how to make a project more consistent with federal or state comprehensive plans. However, FERC is not obligated to include these recommendations in the license or explain its reasons for rejecting them."[118] The comprehensive plans serve only as suggestions.

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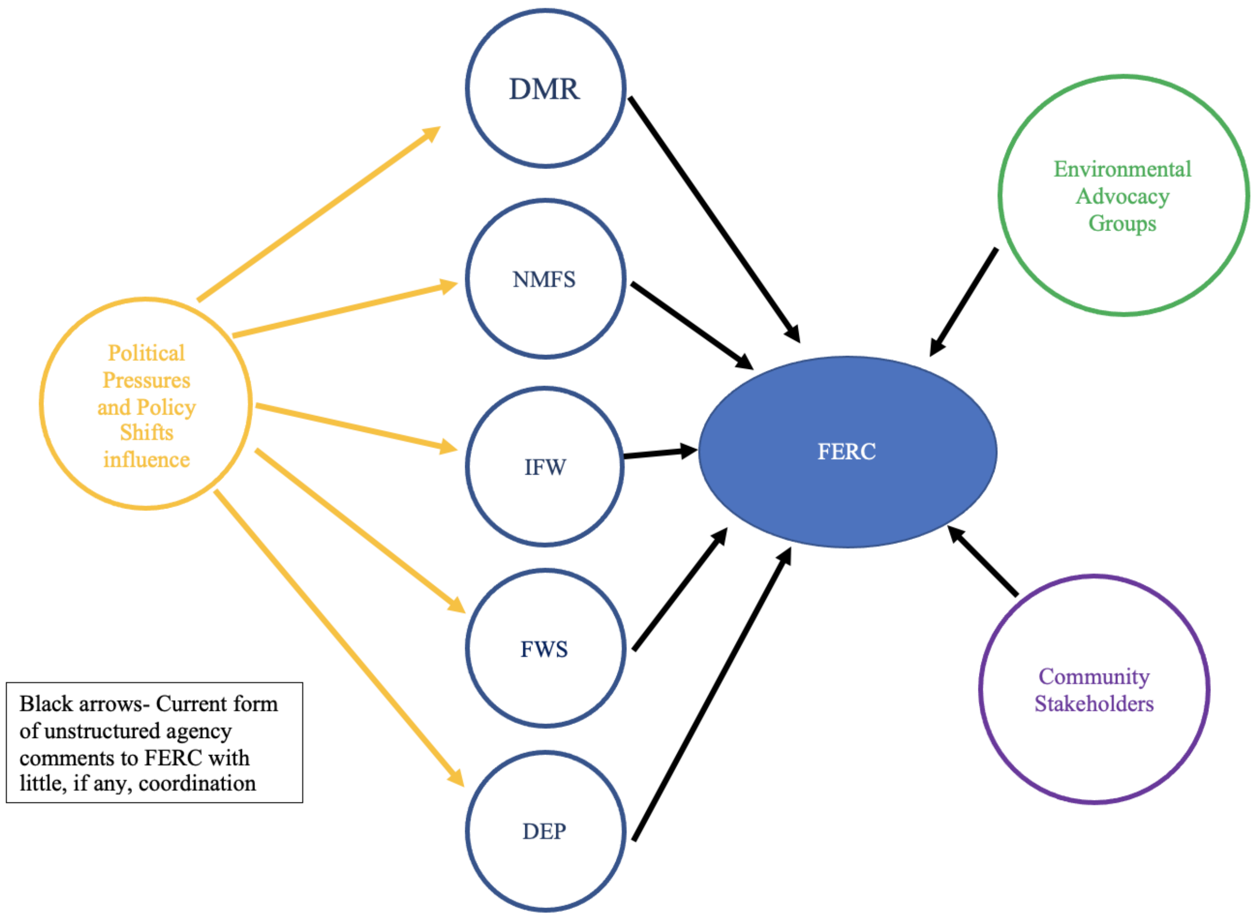
[116] Brookfield Renewable Energy Group, "Ellsworth Hydroelectric Project FERC No. 2727-086 Application for New License for Major Water Power Project – Existing Dam."
[117] ISO New England, "New England's Wholesale Electricity Prices Up in 2018."
[118] U.S. Fish and Wildlife Service, "Overview of the Federal Power Act and the Hydropower Relicensing Process."

Figure 6. Current Structure of FERC Comments



The Kennebec River Resource Plan finds that "due to large impacts on State resources and relatively small generation, the State believes the best approach to meet our management goals for the Kennebec River is to decommission and remove some or all of the dams in the lower Kennebec. These four projects impact five species of diadromous fish and prevent ESA-listed species from reaching high-quality habitat. Any potential lost generation at the lower Kennebec projects, as a result of decommissioning and removal, could be offset by strategic hydropower enhancements at projects that are not significant fish passage impediments and/or through new clean energy developments (e.g. grid-scale solar)."[119] Requiring FERC to address the goals of comprehensive management plans will shift the balance of trade-offs between development and nondevelopment interests toward the latter and potentially result in the denial of licenses.

The next two relevant sections of the FPA consider fish passage infrastructure and other conditions targeting the protection of fish and wildlife resources. Section 10(j) states "that in order to adequately and equitably protect, mitigate damages to, and enhance, fish and wildlife (including related spawning grounds and habitat) affected by the development, operation and management of the project, each license issued under this Part shall include conditions for protection, mitigation, and enhancement" in consultation with relevant resource agencies.[120] This provision is similar to section 10(a) but differs in that FERC is required to provide a detailed rationale for the rejection. Conditions related to anadromous fish passage and protection usually address operating hours, water use limits, and fish passage installation and maintenance standards. Section 18 provides that FERC "shall require the construction, maintenance, and operation [of fish passage infrastructure] by a licensee at its own expense of such ... fishways as may be prescribed by the Secretary of the Interior or the Secretary of Commerce, as appropriate."[121] The United States Fish and Wildlife Service, in the Department of the Interior, and NMFS, in the Department of Commerce, can be directed to mandate fish passage. Their guidance also informs standards for other agencies that may recommend such infrastructure. This provision cannot be rejected or altered by FERC or the licensee.

For the Kennebec River case study, consideration of the cumulative impacts of the four

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[119] Maine Department of Marine Resources, "Kennebec River Resource Management Plan, Diadromous Resources Amendment," 28.

[120] Federal Energy Regulatory Committee, "Handbook for Hydroelectric Project Licensing and 5 MW Exemptions from Licensing," A-14.

[121] U.S. Congress, United States Code: Federal Power Act.

dams results in a greater ecological impact on anadromous fish than assessing the dams individually, as reflected by the goals of the Environmental Impact Statement currently under development by FERC. In order to pass the required number of river herring and other species as specified in the Plan, the dams' fish passage facilities must operate at an extremely high efficiency (greater than 90% for river herring and Atlantic salmon) in order to have a chance of allowing enough fish to pass to achieve viable populations above the dams. According to an analysis by the Maine DMR, fish passage infrastructure will be successful "only if very high-performance standards for fish passage are consistently achieved at each of the mainstem project dams. [Maine] DMR's review of effectiveness studies conducted in Maine demonstrates that our recommended performance standards are not achievable based on current proposed fishways by the Licensee."[122] The report also notes that there are no examples of self-sustaining anadromous fish populations on river systems with four or more dams. Existing fish passage technology is not sufficient to meet fish passage requirements. Fish passage infrastructure installed at the four dams on the Kennebec River would be both expensive to construct and given their low generating capacity, such expenses would likely exceed the economic benefits of hydropower generation from the dams.

As for the Union River, the fish passage consideration is even more important because Graham Lake Dam is unlikely to be removed. The cumulative impacts of two dams on the river require an extremely high passage rate and likely will follow the same path as the Kennebec River case study: currently available fish passage technology will not pass enough fish to produce viable populations upstream of the dams, particularly in comparison to dam removal. Additionally, the Ellsworth Dam is sixty-five feet tall which makes fish passage infrastructure

[122] Maine Department of Marine Resources, "Kennebec River Resource Management Plan, Diadromous Resources Amendment," 35.

infeasible. The Graham Lake Dam is substantially lower which makes fish passage infrastructure a more realistic option. In any case, as the Ellsworth Dam generates limited power, the expense of installing fish passage will likely exceed the economic benefits of generating hydropower.

For the Kennebec River case study, a decision that balances concerns about developmental and non-developmental resources would consider the dams' contribution to the electrical grid, the cumulative impact of fish passage infrastructure on anadromous fish populations, and the spawning habitat blocked by the dams. When equal consideration is given to both developmental and non-developmental resources, it is clear that the dams have a significant impact on anadromous fish passage compared to their very small contribution to Maine's grid. The previous removals case study helps demonstrate the immediate response of anadromous species to dam removals and the evidence collected in the last two decades supports the idea that river herring restoration will be an important component of groundfish restoration in the Gulf of Maine. Additionally, as stated in the Plan, it is unlikely that fish passage infrastructure will result in high enough passage rates to justify the dams' continued presence on the river system. Lastly, improvements in alternative forms of renewable energy make hydroelectric power a less critical resource than when these dams were last licensed which, all together, makes the case in favor of denying the licenses stronger than the case for relicensing the four dams.

The Union River case study has a similar outcome when the "equal consideration" component is applied. The two dams pose a significant obstacle to upstream fish passage while contributing a minimal amount of energy to the state's grid. Decommissioning and removal of the Ellsworth Dam and installation of high-quality fish passage at the Graham Lake Dam would satisfy the goals of the Maine DMR and other resource agencies and is justified given the small amount of power generated by the Ellsworth Dam. In order to ensure adequate fish passage at the Graham Lake Dam, standards for performance and a monitoring regime should be included as conditions of the license. If the passage does not meet standards, a provision mandating improvements, potentially including removal, would ensure that the resource agencies' goals are met. The public interest in power generation from the dam can likely be met by alternative sources of renewable energy.

The results of the case studies demonstrate that strengthening and clarifying of the application of the ECPA amendments would result in a balance between developmental and non-developmental interests that is more favorable to anadromous fish than the status quo. It is possible to engage in removal proceedings on key dams while negotiating trade-offs among dam owners and advocates of removal to result in minimal generation losses and maximum ecosystem health. In the case of dams that obstruct significant habitat and pose significant impacts on anadromous species while generating little power, removal may be the optimal solution. For dams that generate significant amounts of electricity, removal may not be the optimal solution, however; clearer standards will help FERC make more consistent and ecologically sound decisions. Changes to the ECPA amendments to better reflect the intentions of the "equal consideration" language in the amendments will strengthen protections for anadromous fish and add transparency to FERC's decision making process.

Recommendations

This section provides recommendations to modify the provisions of the FPA to promote more transparent decision making that adheres to the goals of the ECPA amendments and ensures that FERC considers current scientific knowledge. This will require congressional action in the form of new legislation to clarify and update the language of the FPA that addresses ecological concerns in the FERC decision making process. This step will also align the regulatory structure with the goals of power generation and ecological restoration that are central components of many states' climate action plans. In the past two decades, since the removal of dams on the Kennebec and Penobscot Rivers, available research points towards an ecological connection between river herring and groundfish, suggesting that groundfish are unlikely to return in substantial numbers without the return of river herring.[123,124] The past removals case study focused on assessing the impact of dam removal on anadromous fish populations and identified specific examples that demonstrate how quickly populations respond following removal and how much higher they are in the wake of removal compared to the use of fish passage infrastructure. This finding, combined with recent research about the value of connected ecosystems and free flowing rivers, warrants consideration in the FERC relicensing process because decisions should be made in light of the best available scientific evidence.

In Maine, there are currently seven dams in the midst of the relicensing process (**Table 2**) and twenty-one dams that will be up for relicensing in the next decade (**Table 3**). The last time these dams were up for licensing was 30-50 years ago and the decision making process reflected the knowledge and societal values of the time. The result was licensing of most dams, many near the head-of-tide that blocked significant portions of the watersheds. Today, more is known about ecosystem function, renewable energy sources, and the impact of dams on the environment so the decision making process should reflect that knowledge. Additionally, there is more knowledge about the connection between freshwater and marine ecosystems, specifically

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[123] Dias, Frisk, and Jordaan, "Opening the Tap."
[124] Hare et al., "A Review of River Herring Science in Support of Species Conservation and Ecosystem Restoration."

regarding the interaction between river herring and groundfish. The recommendations for amending the FPA address the advances in scientific knowledge from a neutral standpoint by requiring FERC to provide reasoning for decisions and providing a decision making guide.

In conjunction with recommendations for reforming the FPA, there are also recommendations regarding resource agency comments to provide a more uniform comment process and ensure that agencies account for the best available knowledge when making comments. Resource agencies can increase the impact of their comments on licensing by shifting from a single species management approach to an ecosystem-based model; this will highlight the importance of connected ecosystems to better inform the non-developmental resource component of licensing decisions. These recommendations will result in decisions that give greater weight to the protection of anadromous fish and better reflect the ecological consequences of dams as required by the "equal consideration" provision of the FPA. The changes are summarized in **Table 6** and discussed below.

Table 6. FPA Recommendations

Section	Current Language	Recommendations
Section 4(e)	"In deciding whether to issue any license under this Part for any project, the Commission, in addition to the power and development purposes for which licenses are issued, shall give equal consideration to the purposes of energy conservation, the protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality [emphasis added]."[125]	*Add specific instructions for balancing developmental and non-developmental resources such as a matrix to guide the "equal consideration" requirement (see* ***Table*** *7)*
Section 10(a)	FERC shall ensure that plans are "best adapted to a comprehensive plan for improving or developing a waterway or waterways for the use or benefit of inter-state or foreign commerce, for the improvement and utilization of waterpower development, for the adequate protection, mitigation, and enhancement of fish and wildlife (including related spawning grounds and habitat), and for other beneficial public uses, including irrigation, flood control, water supply, and recreational and other purposes referred to in section 4(e)"[126]	*Incorporate a requirement for FERC to provide a detailed rationale for decisions related to comprehensive management plans and other resource agency comments*
Section 10(j)	That in order to adequately and equitably protect, mitigate damages to, and enhance, fish and wildlife (including related spawning grounds and habitat) affected by the development, operation and management of the project, each license issued under this Part shall include conditions for protection, mitigation, and enhancement. ...[S]uch conditions shall be based on recommendations received pursuant to the Fish and Wildlife Coordination Act (16 U.S.C. 661 et seq.) from the National Marine Fisheries Service, the United States Fish and Wildlife Service, and State fish and wildlife agencies.[127]	*Establishes a uniform recommendation format that involves a holistic, ecosystem-based approach*
Section 18	[FERC] shall require the construction, maintenance, and operation by a licensee at its own expense of such ... fishways as may be prescribed by the Secretary of	*Add provisions such that (1) this section becomes operative when the "equal*

[125] U.S. Congress, United States Code: Federal Power Act.
[126] U.S. Congress, United States Code: Federal Power Act.
[127] U.S. Congress, United States Code: Federal Power Act.

	the Interior or the Secretary of Commerce, as appropriate.[128]	*consideration" decision determines that developmental resources outweigh non-developmental interests; (2) add standards for fish passage efficiency and the effects of cumulative impacts of fish passage technology at multiple dams on a river; and (3) mandates a monitoring program to ensure that fish passage infrastructure is performing as intended.*

Section 4(e)

*Recommendation: Add specific instructions for balancing developmental and non-developmental resources such as a matrix to guide the "equal consideration" requirement (see **Table** 7)*

The "equal consideration" provision from section 4(e) is intended to address both developmental and non-developmental resources but lacks any firm guidance for FERC to follow. FERC is tasked with the difficult challenge of balancing the electrical generation from dams, which serves the public interest in renewable, affordable power, against the ecological consequences posed by dams. Decisions are made on a case-by-case basis and the many qualitative factors involved result in some degree of subjective decision making. Modifying this section to provide clearer guidelines for FERC about how to balance these interests will make the decision making process more transparent and will better reflect current scientific knowledge.

These guidelines are difficult to quantify but should specifically reference relative levels of power generation and habitat obstruction in assessing the relative merits of development

[128] U.S. Congress.

versus non-development. Below is a table with a decision making matrix to guide the "equal consideration" analysis based on relative levels of river obstruction and power generation posed by a dam. The power generation component is based on dams currently operating in Maine divided roughly in thirds. The river obstruction component is a subjective measure that changes based on how obstruction is calculated. The general guideline for obstruction is based on the dam's location on the river from head-of-tide to middle river to upper river. This matrix serves as a rough approximation on which to base FERC decision making. The extreme cases of low generation with high obstruction and high generation with low obstruction result in easier decisions. The middle cases are then selected for further analysis before reaching a final decision on licensing.

Table 7. Equal Consideration Matrix

	Low Power Generation (Less than 5 MW)	**Medium Power Generation (Between 5 MW and15 MW)**	**High Power Generation (Greater than 15 MW)**
Head-of-tide Obstruction	Deny license	Deny license	Evaluate further, focusing on potential productivity of watershed and other dams on the river
Middle River Obstruction	Deny license	Evaluate based on potential productivity of watershed and other dams on the river	Evaluate based on potential productivity of watershed and other dams on the river
Upper River Obstruction	Evaluate based on potential spawning habitat above the dam and other dams on the river	Relicense	Relicense

Table 7. *Matrix with guidelines for decision making based on relative levels of obstruction and power generation of a dam. Power generation amounts were determined by the current breakdown of hydroelectric dams in Maine. Obstruction is difficult to precisely define due to other obstructions and method of calculation. This is a matrix meant to serve as a guideline for the beginning of the decision making process.*

The overall assessment will be required to consider the available information about the connection between freshwater and marine ecosystems in order to adequately address the impacts of dams on non-developmental assets. Current or potential availability of replacement power should be a factor in the decision. The last modification to this section is a mandate that FERC provide the rationale for their decision that explicitly lays out the analysis of "equal consideration" which will enable decisions to be better understood by all involved parties. By clarifying section 4(e) to be more clear about intentionally considering the impact of non-developmental factors, including potential denial of relicensing, and requiring FERC to provide detailed reasoning for their decision about the "equal consideration" provision, the process will be more transparent and will result in more consistent decisions which reflect the reality of current developments in the field of renewable energy and integrate current ecological knowledge.

Section 18

Recommendation: Add provisions such that (1) this section becomes operative when the "equal consideration" decision determines that developmental resources outweigh non-developmental interests; (2) add standards for fish passage efficiency and review of cumulative impacts of multiple dams on a river; and (3) mandates a monitoring program to ensure that fish passage infrastructure is performing as intended.

A related factor to the "equal consideration" language of the FPA is the section 18 provision, which allows FERC to mandate the construction of fish passage infrastructure as a condition of licensing. This provision has been used in the past as a method of balancing developmental and non-developmental factors but as discussed in the case studies, fish passage infrastructure is not as effective as facilitating upstream passage as dam removal. This is especially true when there are multiple dams on one section of river because the cumulative impacts of dams on fish passage can result in inadequate passage rates overall. This issue is a focus of the ongoing Environmental Impact Statement process for the four dams on the Kennebec River discussed above.

Amending section 18 to specify that fish passage infrastructure should be used only in cases where the section 4(e) decision determines that developmental interests outweigh non-developmental interests will ensure that cases are decided from a neutral standpoint without privileging existing infrastructure. In cases where non-developmental assets outweigh developmental assets, this change will ensure that fish passage infrastructure is not used as a compromise given the current knowledge about the shortcomings of the technology. When the "equal consideration" provision of section 4(e) indicates that the dam in question should be relicensed, fish passage is the best tool to facilitate upstream access even if it is not as effective as dam removal. This will likely occur in cases where hydro generation contributes a substantial amount of power to the grid, on low height dams where fish passage infrastructure is more effective, or cases where the costs of dam removal are high, such as the Graham Lake Dam. Incorporating penalties for failure to meet the standards, including potential revocation of the dam's license, will create accountability. By setting standards and providing a scheme to monitor said standards, companies will have an incentive to comply while environmental advocacy groups and resource agencies can be assured that the inclusion of fish passage infrastructure is done in a constructive manner that enables substantive passage rates to best meet the goals of comprehensive plans.

Sections 10(a) and 10(j)

Recommendation: Incorporating a requirement for FERC to provide a detailed rationale for decisions related to comprehensive management plans and other comments from resource agencies

Sections 10(a) and 10(j) address comments from resource agencies and the role of state comprehensive plans in the FERC decision making process. Currently, regarding section 10(a), FERC is not obligated to accept comments nor is it required to document its rationale for rejecting such comments. Amending section 10(a), which considers comments from state comprehensive plans, involves adding a requirement for FERC to either accept the comments or provide detailed reasoning for a rejection of the comments, such as in the case of dams that provide significant power generation or flood control benefits. This will ensure that the benefits of non-developmental resources, such as anadromous fish, are considered more thoroughly. In the case of the Kennebec River Resource Plan, the state clearly calls for the removal of the four dams due to their impact on anadromous fish species relative to their minor contribution to the state's grid.[129]

Resource Agency Comments

Section 10(j) already contains a provision that requires FERC to either accept the conditions recommended by resource agencies or provide detailed reasoning for their rejection. The recommendation in this section relates to the role of the resource agencies in section 10(a) and 10(j) to suggest a uniform recommendation format that takes a more holistic approach considering the broader ecosystem impacts of a dam. A wide range of resource agencies may submit comments for the FERC process, covering fisheries management to water quality management to other ecological issues. Modifying the FPA to require reasoning from FERC for decision making will benefit all resource agencies; this analysis is limited to fisheries management agencies.

State resource agencies are charged with creating management plans for river systems but may have different goals. For example, the Maine Department of Inland Fisheries and Wildlife is responsible for management of recreational fishing and hunting while the Maine Department of Marine Resources is responsible for marine and estuarine fisheries management. Federal agencies, such as NMFS and ASMFC, are responsible for the management of commercial fisheries in the Gulf of Maine. One potential mechanism to align agency comments would be to use an ecosystem-based approach in developing comments to be submitted to FERC.

An ecosystem-based approach goes beyond the traditional single-species management

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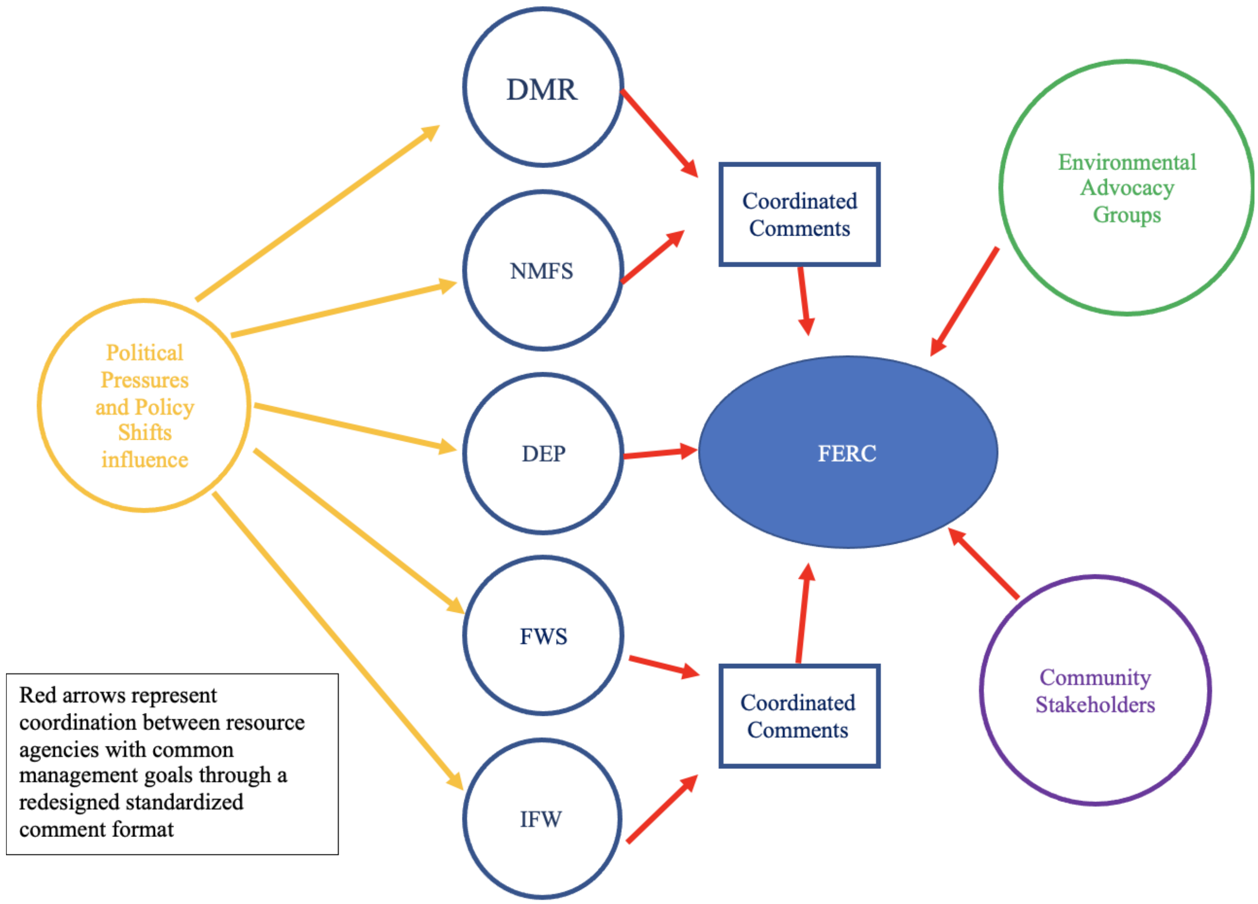
[129] Maine Department of Marine Resources, "Kennebec River Resource Management Plan, Diadromous Resources Amendment," 35.

paradigm followed by fisheries management agencies and enables a more holistic assessment of a proposed action's impacts. Single-species based management incorporates limited ecological drivers in the decision making process, often focusing on natural mortality and productivity of the species. This approach fails to account for interactions between species and between different ecosystems which may result in poor management outcomes. Within the Gulf of Maine, groundfish rely on smaller species, including river herring, for food. A more holistic approach will consider interactions between species and flows between ecosystems; it will also allow align comments from resource agencies with overlapping management goals. An ecosystem-based approach will benefit resource agencies by acknowledging that species management and restoration are complex processes. Coordinating the approach for multiple species will better account for the connection between different trophic levels and increase the likelihood of successful restoration. A holistic, coordinated approach to resource agency comments is likely to reinforce the importance of river herring in the ecological structure of the Gulf of Maine.

Figure 7. Suggested Modifications to FERC Comment Structure



The holistic assessment will approach the comments from an ecosystem scale in order to account for the variety of factors that drive fish population dynamics. Resource agencies will be tasked with providing comments that account for the role of river herring and other affected anadromous species within their sphere of management. Comments from NMFS and ASMFC focus on role of river herring in marine food webs while Maine DMR's comments will address the role of river herring in both marine and freshwater ecosystems. One way to achieve the goal of an ecosystem-based approach to comments is through a standardized format. Congressional legislation amending the FPA based on the recommendations of this paper will instruct FERC to develop a standardized comment format. By utilizing a standard format, comments from different agencies can more easily be compared with one another. Another benefit to the standardized format is that resource agencies with overlapping goals will be able to work together when developing management plans as part of the comment process.

This approach aligns closely to the related ecosystems component (ECO) of the SES Framework and allows resource agencies to provide comments that more accurately account for the impact that dams have on river herring, other anadromous species, and related species. The potential benefits of river herring population restoration go well beyond the species itself and those benefits will be accounted for in a more holistic assessment by resource agencies. By using an ecosystem-based approach, the ecological scale of analysis will be broader and will demonstrate the impact of river herring beyond the immediate area surrounding the dam in question. The recovery of river herring and other anadromous species is an important goal for the State of Maine and is a necessary, if not sufficient, step to help with the recovery of groundfish populations. The approach discussed above aims to present a reasonable modification to how resource agency comments in the FERC process are currently developed in order to better account for the connections among species and between ecosystems. The ecosystem-based approach addresses the impacts of dams on river herring and other anadromous species along with the impacts of anadromous species on the Gulf of Maine ecosystem, specifically related to the role of river herring as forage for groundfish.

This strategy is based on the concepts of Ecosystem-Based Management and Ecosystem-Based Fisheries Management. The complexity of interactions within an ecosystem and the research and monitoring necessary to understand the variety of factors that impact ecosystems present challenges for fully implementing EBM and EBFM. The ecosystem-based approach suggested for resource agency comments will begin to shift management practices away from the traditional single-species paradigm without unnecessarily burdening these agencies. A shift to Ecosystem-Based Management is occurring slowly and will be a possibility on a wider scale in the future. Aligning the work of resource agency comments with EBM principles today will help provide inputs for developing Ecosystem-Based Management plans in the future.

Beyond Dam Removal and the FERC Process

Ecosystem-based management stems from the reality that ecosystems are complex, multi-level systems, which can be affected by changes in any one part of the whole. Instead of the more traditional, single-species perspective, management plans can better account for predator and prey relationships and the impact of habitat conditions. The concept of ecosystem-based management has been discussed for many decades; implementation will require a paradigm shift and there are many vested interests in the current system. EBFM will also require a shift in monitoring and research currently conducted by resource agencies to include many variables beyond those monitored for stock assessments. The past two decades have produced important research, however, about the benefits of EBFM and the general outlook is beginning to shift towards taking such an approach.

Ecosystem-based management is especially important in marine and freshwater ecosystems due to the complexity of interactions between species. An EBFM approach enables regulators to account for interactions when making fisheries management plans. EBFM aims to acknowledge the connections among species within the ecosystem including humans.[130] By accounting for these connections, management can focus on the cumulative impacts of changes within a system, strive to meet multiple management objectives for different components of the

[130] Karen McLeod and Heather Leslie, eds., *Ecosystem-Based Management for the Oceans* (Washington, DC: Island Press, 2009).

system, and achieve a better understanding of how different components of the ecosystem interact with each other.[131] It is difficult to recover species when using a single species management plan because when many species are depressed, interactions between the species can go overlooked in single species management plans. In the case of river herring and cod, while river herring declines were not the primary driver of the cod population collapse, rebuilding river herring populations will be important for the cod populations' recovery. An ecosystem-based approach to management in this case will elucidate these connections and make clear their role in the dynamics of connected species.

The Chesapeake Bay is one location where Ecosystem-Based Management has been practiced for an extended period of time; the shift occurred in the 1970s when seagrasses began to die off, resulting in a working group that pushed for a holistic management strategy to best account for the connections within the food web.[132] This effort grew into a full-scale EBFM approach to governing the Chesapeake Bay ecosystem to address the effects of pollutants on the system and took an ecosystem approach due to the many different organisms that were being affected.[133] Once the basis for the ecosystem approach was established in the Chesapeake Bay, fisheries managers have been able to make changes in regulations for a variety of organisms in the system by accounting for interdependence and resulting in decisions which better reflect the ecological complexity of aquatic ecosystems.

Management now focuses on the connections among different levels of the food web, specifically on striped bass, blue crab, Eastern oyster, menhaden, and shad, to better manage

[131] McLeod and Leslie.
[132] Heather M. Leslie, "Value of Ecosystem-Based Management," *Proceedings of the National Academy of Sciences* 115, no. 14 (April 3, 2018): 3518–20, https://doi.org/10.1073/pnas.1802180115.
[133] McLeod and Leslie, *Ecosystem-Based Management for the Oceans*.

depressed populations that rely on each other.[134] One species to benefit from this approach is the Atlantic menhaden, a small forage fish abundant in the Chesapeake Bay. The ecosystem focus of the management plan recognizes the importance of all trophic levels in creating a healthy ecosystem. River herring fall into the same category as Atlantic menhaden: forage plays an important role in sustaining a resilient ecosystem. The benefits of taking this type of approach to fisheries management are well supported by the existing literature and the movement towards implementing an EBFM approach is gaining momentum.[135,136] The primary difficulty of establishing EBM and EBFM on wide scale is the significant shift required to change a single species management strategy to an integrated, ecosystem focused approach. It is also difficult because significant monitoring and research is necessary to understand the complexities of ecosystems. The ecosystem-based approach suggested for resource agency comments to FERC is one step towards Ecosystem-Based Management and enables agencies to begin compiling inputs necessary to formulate an Ecosystem-Based Management plan.

Conclusion

Overall, the FERC process is currently construed to account for the effects of dams on anadromous species; however, in actuality, the decision making process often undervalues ecological concerns. The above recommendations apply a more robust understanding of river herring ecology to the regulation of hydroelectric generation. Expanding the scope of FERC's analysis to include marine ecosystem impacts will benefit marine and freshwater ecosystems by strengthening coastal food webs and increasing the resilience of freshwater and coastal

[134] Sea Grant Maryland, "Ecosystem-Based Fisheries Management" (University of Maryland, n.d.), https://www.mdsg.umd.edu/topics/ecosystem-based-fisheries-management/ecosystem-based-fisheries-management.
[135] Jeremy S Collie et al., "Ecosystem Models for Fisheries Management: Finding the Sweet Spot," *Fish and Fisheries* 17, no. 1 (March 2016): 101–25, https://doi.org/10.1111/faf.12093.
[136] Michael J. Fogarty, "The Art of Ecosystem-Based Fishery Management," ed. Kenneth Rose, *Canadian Journal of Fisheries and Aquatic Sciences* 71, no. 3 (March 2014): 479–90, https://doi.org/10.1139/cjfas-2013-0203.

ecosystems to climate impacts. The recommendations will result in a more transparent and consistent decision making process, which is beneficial for all parties involved. While it is not a realistic goal to remove every dam in Maine, despite the undeniable benefits for river herring, it is possible to engage in strategic removal to achieve a better balance between ecosystem connectivity, public interest in power generation, and the interests of community stakeholders.

This project focuses only on FERC relicensing of hydroelectric facilities. In Maine alone, there are many unregulated dams, which are small and often on tributaries of major rivers or small coastal watersheds, that impede access to spawning grounds. There is no organized process to identify and remove these obstacles because most are privately owned. Working to facilitate access from major rivers and tributaries all the way to spawning ponds and lakes is an important next step in restoring river herring and other anadromous species populations.

The previous removal projects on the Kennebec and Penobscot rivers highlight another important component of restoring upstream access for anadromous species: the difficulty of funding the removal of a dam after it is denied a license or if the owner decides to pursue removal. This project focuses on the relicensing process which may result in the denial of a license but does not mandate removal. Facilitating the actual removal of dam infrastructure can be an expensive and difficult process. The Edwards Dam case study demonstrates the necessity of creative negotiations when engaging in removal: the removal was effectively stalled until Bath Iron Works stepped in to provide funds for removal. The funding allowed Bath Iron Works to meet requirements for ecosystem restoration related to their expansion onto sturgeon spawning wetlands.

The Penobscot Project shows the power of outside interests in the dam removal process and illustrates a complement to the FERC process to achieve dam removal. Bypassing the FERC process through the use of a trust to purchase dams from companies and working with FERC to allow for generation increases at upstream dams resulted in a solution that satisfied all parties.

Future removal projects, such as the dams discussed on the Kennebec and Union rivers should relicensing be denied, will require significant funding to complete the decommissioning and removal process: this means that private groups will likely need to raise funds and engage with state and federal government agencies to acquire additional funding. One potential solution to this problem might involve companies that own dams engaging in negotiations with government agencies and environmental groups to provide for strategic dam removal while guaranteeing upstream dams' continued operation or increased generation over a set timescale. These types of creative solutions are important because it does not make sense to deny a license and reduce renewable power generation without finishing the process of removal that is necessary to restore anadromous species.

Going forward, it is important to capitalize on the results of removal projects of the past three decades and the changing energy options available to policymakers to rebalance considerations of developmental and non-developmental concerns. The recommendations amending the FPA serve to align the FERC process with current scientific knowledge and growing opportunities for alternative sources of grid-scale renewable power such as wind and solar. These steps will lead to more resilient ecosystems and a cleaner power grid, both of which are important to mitigate and adapt to climate impacts. Decisions about dam removal are difficult and involve many factors but given current knowledge and motivation on behalf of all parties involved, it is distinctly possible to arrive at solutions that prioritize both ecological considerations and the public interest in clean power generation while not significantly impacting the operation of companies that own dams.

The impact of dam removal projects occur on multiple time scales. It is important to recognize that even though dam removal will result in short-term economic and other costs, the benefits that materialize in the long run outweigh these costs. In the short run, dam removal projects on a wide scale may necessitate a short-term increase in fossil fuel usage as the transition to wind and solar will take time. Other short-term costs include lost tax value for municipalities and job losses that may be, at least, partially offset by added recreational value and taxation of solar and wind assets. Dam removal projects will also impact the ecosystem due to heavy machinery use and the outflow of sediment from dam sites. In the long-term, however, the benefits of healthier ecosystems, more sustainable food webs, and potential revitalization of important commercial fisheries in Maine will outweigh these short-term costs.

Future removal projects will contribute to a better understanding of the connection between river herring and groundfish. It will be important to monitor the results of dam removals and adapt policies accordingly. The decision making process should rely on the latest available evidence to best account for all of the factors that complicate decision making in marine and freshwater ecosystems.

A goal related to the restoration of river herring is the rehabilitation of groundfish populations in the Gulf of Maine. As discussed above, while river herring will not be the only driver of groundfish restoration, they are an important component of recovery. The recovery of groundfish populations will restore a historically important industry to the coast of Maine, bring significant economic value back to the state of Maine, and help struggling coastal towns. Unfortunately, climate change and warming waters have heavily impacted the Gulf of Maine and may prove to be a fatal blow to the depressed groundfishery with a vulnerability analysis finding the Atlantic cod and other groundfish have a high potential for northward shifts.[137] Atlantic cod in the Gulf of Maine are particularly vulnerable to warming waters as this is the southern edge of their range.

A recent study conducted by NOAA researchers found that northward migration is likely in the coming decades as global warming is predicted to continue and results in significant northward shifts for many species even in the scenario where nations meet their pledges from the Paris Climate Accords.[138] The northward shift of species will inevitably result in alternative species entering the Gulf of Maine to occupy the niche currently occupied by the limited groundfish stocks. River herring will likely serve as forage for the species that move into the current groundfish niche making their recovery important even without today's groundfish species. Overall, recovery of river herring populations will be essential to fortify marine food webs in the face of climate change, making the Gulf of Maine ecosystem more resilient and robust. A more resilient ecosystem will be better equipped to handle changes as a result of warming waters due to climate change, giving the organisms of the Gulf of Maine and the people that rely on the Gulf of Maine the best chance of maintaining productivity.

Working towards restoring fish populations on all trophic levels and promoting a more resilient Gulf of Maine ecosystem will hopefully enable the recovery of the previously productive commercial fisheries. The commercial fisheries were worth millions of dollars prior to the collapse in 1992 and have the potential to be worth millions of dollars today should recovery occur. The exact value is difficult to quantify today given the number of unknown

[137] Hare et al., "A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf."

[138] James W. Morley et al., "Projecting Shifts in Thermal Habitat for 686 Species on the North American Continental Shelf," ed. Brian R. MacKenzie, *PLOS ONE* 13, no. 5 (May 16, 2018): e0196127, https://doi.org/10.1371/journal.pone.0196127.

factors and level of recovery but will contribute to making up lost economic value due to dam removal. The goals of recovering populations for ecological resilience along with recreational and commercial value are not mutually exclusive but the commercial fisheries are dependent on a robust recovery and resilient ecosystem. The first task for regulators is to recover river herring and groundfish populations to enable higher quotas in the fishery. This recovery, however, is far from certain and relies on many different interests aligning to achieve recovery goals. Accurately assessing the impacts of dams on multiple ecosystems and establishing a decision making framework that balances developmental and non-developmental interests is one of the first steps toward these goals.

Overall, this project attempts to provide a framework for updating the FPA to promote decision making that better aligns the FERC process with requirements in the FPA to balance the public interest in power generation with ecological concerns. In making the FERC decision making process more transparent, the goal is to provide all interested parties with more information on the basis for decisions. The result of the changes suggested will bring the FERC process into alignment with the most recent scientific evidence and will create a win-win situation for ecological concerns and power generation. Decisions that are guided by the best available science will result in the denial of licenses for the ecologically worst dams: those that obstruct significant portions of potential spawning habitat while generating limited power. The four dams examined on the Kennebec River and the two on the Union River are prime examples. New technologies enabling wide scale use of solar and wind power and plans for significant increases in solar and wind usage in Maine in the next decade give regulators options to source renewable energy while enabling the restoration of anadromous species populations.

The State of Maine is at a critical juncture with regard to the future of renewable energy, aggressive climate change mitigation and adaptation goals, and concerns about ecological health. The next decade presents an opportunity for Maine to make substantial changes to further its climate action plan while advancing ecological restoration efforts. Changes in the FERC process will encourage decisions that adequately balance power generation concerns with ecological concerns, favoring removal of head-of-tide and middle river dams. Dam removal efforts pair well with climate action goals by increasing ecosystem resilience to climate impacts. Undertaking these actions will contribute to the restoration of rich natural resources that have always been central to life in Maine. Restoring the groundfishery is an aspirational goal and river herring restoration is an important step in that direction. Should these goals be achieved, countless coastal Maine towns will be revitalized, and hundreds of fishermen will be able to provide for their families and communities. The past three decades have been grim for the groundfishery and those that depend on it, but it may yet have a future. Climate change will likely bring significant change to Maine, but every step taken now, before it is too late, will help mitigate its effects and set Mainers up for the best long-term future. Dam removal alone will not be enough, but it is an important component of a multi-pronged approach that can result in ecological restoration on multiple levels and economic prosperity for the people in Maine who depend on Maine's abundant natural resources.

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