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Passing Judgment on Fish Passage Technologies

Introduction

In the early 1900s, the installation of the Elwha and Glines Canyon dams across the Elwha River completely blocked the course of the salmon which once navigated the river each year to their annual breeding site.[1] The salmon population was decimated, and the Lower Elwha Klallam Tribe, which lived along the river, lost the supply of fish they once relied on.[2] In 1995, government officials judged that the environmental damage the dam was causing merited a $26.9 million[3] dollar removal project. When considering other rivers currently blocked by hydropower dams, policymakers are asking themselves the same question: how much are fish worth?

On the surface, hydropower appears to be a very attractive energy source which is both renewable and often cost competitive with fossil fuels. Figure 1 compares the levelized cost of electricity for various energy sources, ranking hydropower as more cost effective than conventional coal, nuclear, or any renewable energy source. Although most ideal hydropower locations in the United States have already been dammed,[7] many developing nations, primarily located in Asia and South America, are considering hydropower as a potential solution to their country's rising energy needs.[4] Unfortunately, hydropower's attractive exterior conceals substantial environmental costs, including the harm inflicted on fish populations which can no longer freely navigate the river. In order to decide whether hydropower is a viable contributor to a nation's clean energy future, it is important to determine the scope of these environmental dangers how easily they can be mitigated. This paper discusses the challenges involved with implementing fish passage technologies and evaluates how environmentally friendly hydropower is in the area of fish passage.

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[1] http://www.ferc.gov/EventCalendar/Files/20041018094218-fish-pass-final-report.pdf
[2] http://ehp.niehs.nih.gov/120-a430/
[3] http://www.nps.gov/olym/learn/nature/elwha-faq.htm
[4] http://www.forbes.com/sites/jamesconca/2014/11/04/the-hidden-cost-of-hydroelectric-power/#2823f33e114e

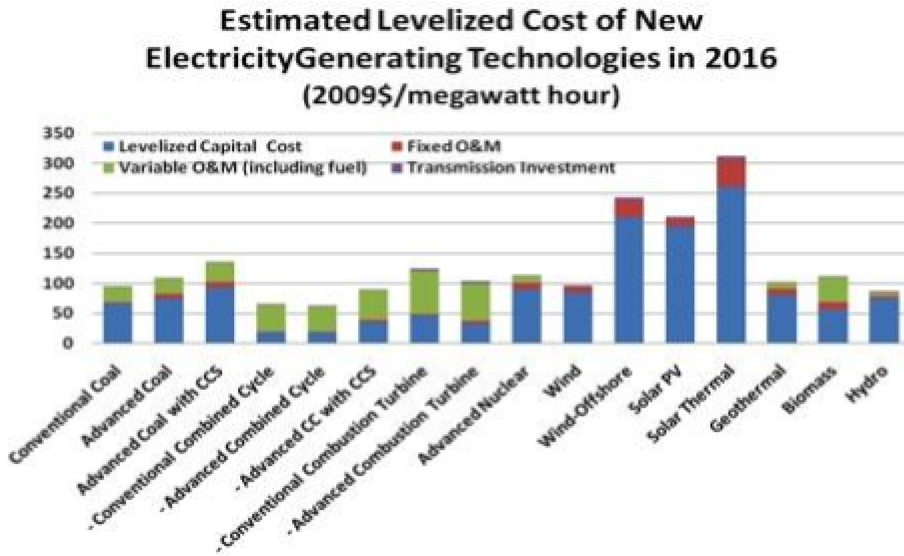

Figure 1: Cost of various conventional and renewable energy sources, estimated from the Energy Information Administration's 2011 Annual Energy Outlook.[11]

Why Fish Passage Matters

A hydropower dam without an effective solution to the challenge of fish passage can wreak havoc on an ecosystem. Pacific salmon, for instance, are an important food source for 137 other species. As they migrate upriver to spawn annually, they transport marine minerals which are essential to river ecosystems. In fact, trees on the banks of spawning rivers gain 22-24% of the nitrogen in their foliage from salmon and grow almost three times as fast as trees on rivers where salmon do not spawn.[6] Healthy tree growth in turn prevents erosion of soil along river banks. If fish are not able to effectively navigate dammed rivers, the entire ecosystem will suffer. Many fish are also central to the economy. Pacific salmon, for instance, support a $3 billion fishing industry which involves over 10,000 jobs per year.[6] The depletion of fish in

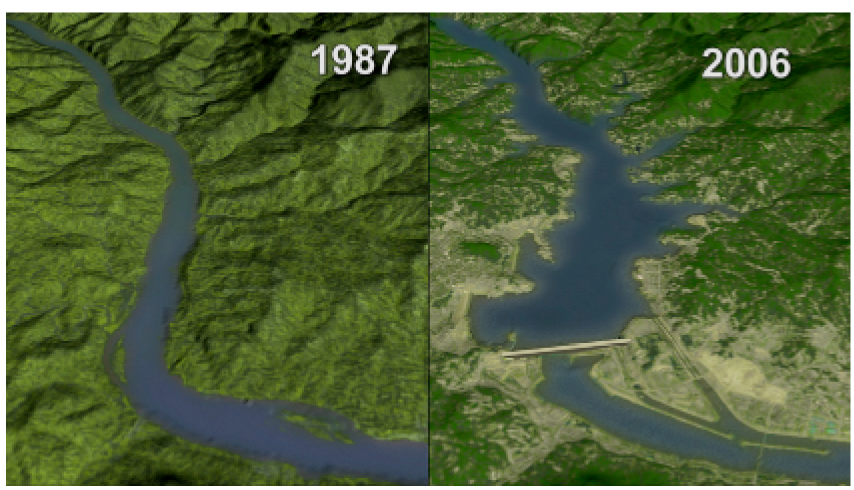

Diagram showing environmental changes since Three Gorges Dam was installed on the Yangtze River in China. Not all the visible changes are necessarily a side affect of poor fish passage, however.

rivers is an economic as well as ecological nightmare. For these reasons, fish passage technologies have become a regular part of hydropower projects.

How Fish Passage Works

To understand the challenges and complexities of fish passage, we must first understand how hydropower works. Most hydropower plants can be broadly divided into two categories: conventional hydro, which involves damming or significantly diverting a river, and microhydro, which uses in-stream technologies to generate power from smaller turbines, often located within the flowing river.[5] This paper focuses solely on conventional hydroelectric dams, which leave a far greater environmental footprint and require more elaborate measures to minimize fish fatalities.

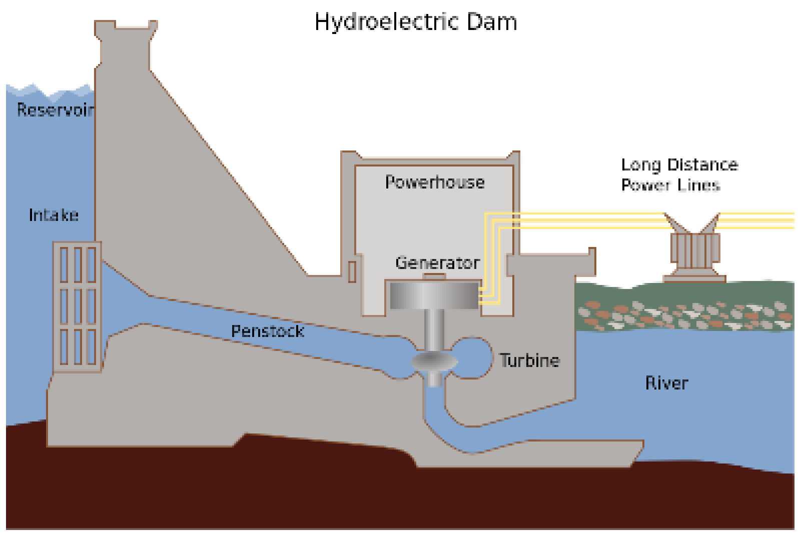

Figure 2: Diagram of a conventional hydropower dam.[9]

A traditional hydropower plant is constructed by obstructing the course of a river with a dam. With the flow restricted, a large reservoir forms upstream of the dam. Water flows through an intake, where the potential energy of the water is converted into kinetic energy of a spinning turbine.[6] This energy is then converted to electrical energy, as shown in Figure 2.

Without effective fish passage techniques, dams severely disrupt the passage of fish up and down the river. The harmful effects of dams are often most pronounced in populations of anadromous fish such as salmon and alewife, which spend their lives in the ocean but migrate upstream to breed. Without upstream fish passage technologies, many fish are unable to find their way to breeding grounds and are unable to reproduce. Trapped just below the dam, they are vulnerable to predators which can further destroy the fish population. If fish do find themselves above the dam, navigating the dam heading downstream can be just as difficult. Fish can be de-scaled or killed by being sucked into turbine blades. Even fish which are not directly hit by the turbine frequently are wounded or killed by barotrauma - physical harm from the rapid change in barometric pressure between the bottom of the reservoir and the surface-level water on the other side of the dam. To adjust to the new pressure, the fish's swim bladder swells rapidly and may rupture. The fish's eyes bulge, and its stomach may burst through its mouth.[7]

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[5] http://energy.gov/energysaver/microhydropower-systems
[6] https://en.wikiversity.org/wiki/Power_Generation-hydro_Power
[7] https://www.sciencedaily.com/releases/2014/04/140414140802.htm

Along with anadromous fish, studies have also shown that dams are detrimental to freshwater fish and catadromous species (such as the American eel), which live in freshwater but travel to the ocean to lay eggs.[8]

To address these issues, an array of fish passage technologies have been implemented, each of which transports fish either upstream or downstream. Most upstream fish passage technologies come in one of two general categories. Fish ladders (and similar devices where fish travel through a series of slots or pools), shown in Figure 3, allow fish to swim up a series of elevated pools. Fish elevators, lifts, and locks involve crowding fish into a small container and then lifting them over the dam. Technologies to let fish pass downhill include physical barriers such as screens or nets across the turbine intake coupled with bypass pipes or sluices which carry the fish safely to the other side of the turbine. Fish are directed to these bypasses through sounds, lights, and racks. Alternatively, dams can periodically spill water over the top of the dam, carrying fish with them. Both upstream and downstream passage can be achieved through the typically costly "trap and truck" method of capturing fish and transporting them to the other side of a dam (or a series of dams).

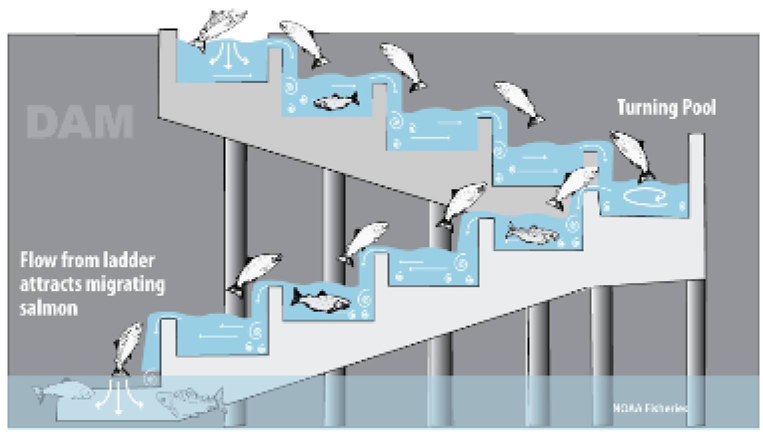

Figure 3: A salmon fish ladder.[8] Fish ladders are generally species-specific.

The Big Question: Is Fish Passage Working?

Although there are a variety of options available for fish passage, there is no guarantee any particular one will be effective in any particular scenario. Since healthy fish populations are so essential to our environment and economy, it's essential that the hydropower industry ensure that fish passage technologies actually pass fish in large enough numbers to maintain healthy populations. We have to ask ourselves one big question: is fish passage working?

Unfortunately, there is no easy answer to this question. As stated in a technology assessment prepared for Congress, "There are no 'sure things' in the world of fish passage technology."[9] Determining whether fish passage measures are working is challenging, as fish passage technologies have highly variable effectiveness. Some dams perform beautifully, like Little Falls Dam in Minnesota, which passes over 100,000 migrating blueback herring per year,[10] but in the most extreme cases, fish passages may do more harm than good. West Enfield Dam in Maine, for example, found that more fish fatalities occurred in the bypass created to let fish pass uphill than had been killed by the turbines themselves.[11] How well a fish

[8] http://www.westcoast.fisheries.noaa.gov/fish_passage/about_dams_and_fish/fish_ladders.html
[9] http://ota.fas.org/reports/9519.pdf
[10] http://ota.fas.org/reports/9519.pdf
[11] http://www.ferc.gov/EventCalendar/Files/20041018094218-fish-pass-final-report.pdf

passage is working may also depend on which species is being considered. The Buchanan Dam in Texas, for example, used a vertical slot fish ladder which passed an estimated 92% percent of chinook salmon but only 69% of steelhead trout.[12] Each dam faces a unique array of environmental concerns and technological challenges. As a result, it is extremely difficult to quantify overall how environmentally costly an average hydropower plant will be. Despite this, recent evidence suggests fish passage may not be doing its job.

For a long time it has been difficult to accurately assess whether as an industry fish passage is effective. Although individual dams may privately record how many fish pass their dam, there is no centralized location where the data is collected to determine the cumulative effect on species which must navigate rivers blocked by multiple dams. In 2013, a fish ecologist named Jed Brown led a team of researchers which conducted a study of several dams located along three major East-coast rivers.[13] His results were not reassuring. His team found that "[fish passage] targets are being missed by orders of magnitude… The goal at the first Connecticut River dam is 300,000 to 500,000 fish. There, the mean for those same years was 86. And for the Susquehanna, the goal is 5 million river herring spawning above the fourth dam, which passed an average of seven herring from 2008 to 2011."[14] Although some dams were extremely good at passing certain species of fish, on the whole, the study came to one unsatisfactory conclusion: modern fish passage technologies are not working well enough. Unless constructors of dams can rethink fish passage, hydropower can never become a clean, green energy source of the future.

Where We Can Do Better

Fortunately for the path ahead, there are specific areas which require the most improvement. Although the range of effective methods for upstream fish passage is generally well-understood, downstream fish passage technologies are often less reliable and less extensively tested. Unlike with upstream fish passage, where it is reasonable to estimate the size and swimming ability of most migrating adults of a certain species, downstream fish passage must be able to serve adults and juveniles, which come in a range of sizes. Along with the potential harm to all fish from the large fall over a dam in spillway solutions or the high water speeds of sluiceways, juveniles face the additional challenge of arriving in a timely manner. If juvenile salmon, for instance, do not swim to freshwater within 15 days, they may lose the ability to switch from freshwater to saltwater when they arrive. It may take too long for these fish to discover bypasses through dams. On the Snake River, for example, a downstream journey which took three days on the undammed river currently may take up to 39 days, a delay which results in a 95% juvenile salmon mortality rate.[15] Another daunting challenge is the problem of directing fish dispersed throughout a large reservoir toward a small bypass over or through a dam. Solutions to this challenge involve careful positioning of bypasses so the river's flow naturally directs fish toward them, as well as using an exotic array of behavioral technologies, including sound, lights, air bubbles, and electricity.[16]

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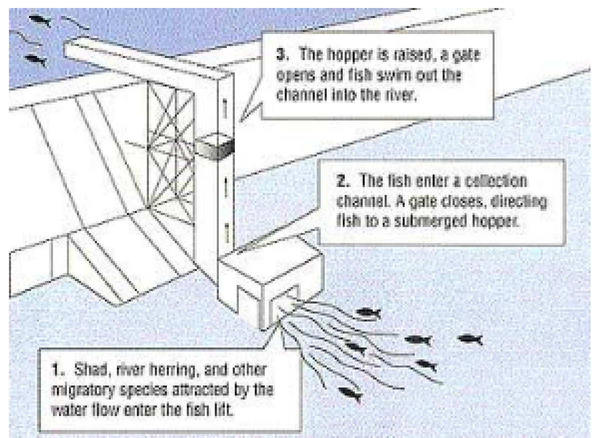
[12] http://www.osti.gov/scitech/servlets/purl/392793/
[13] http://www.sciencemag.org/news/2013/01/fish-ladders-and-elevators-not-working
[14] http://www.sciencemag.org/news/2013/01/fish-ladders-and-elevators-not-working
[15] https://www.internationalrivers.org/dams-and-migratory-fish
[16] http://www.fws.gov/midwest/sturgeon/documents/glcoordmtg04/Amaral-STNCoordMtg04.pdf

Most of these, however, are less effective than physical barriers.[17] Several researchers agree that more research on downstream fish passage is needed. In fact, the Bureau of Reclamation, a government agency which is the second largest producer of hydroelectric power in the country, is currently offering a $20,000 prize for innovative new downstream in a competition beginning March 31, 2016.[18] Until downstream fish passage is improved, anadromous fish will be unable to safely complete their lifecycles.

A second area where fish passage at hydropower dams is often lacking is in fish passage for freshwater fish. Although they typically do not undergo the same extensive migrations as anadromous fish, they still move throughout rivers and may become caught in turbines. Unfortunately for our slippery little friends, fish passage strategies are typically designed for common migratory fish such as salmon, shad, and herring, and they often fail miserably at suiting the needs of other species. Fish ladders build for salmonids and other large, powerful, anadromous fish frequently cannot pass freshwater fish such as lake sturgeon, which may have weaker swimming skills and less jumping ability.[19] The problem is avoided with fish lifts and elevators like that shown in Figure 4,[20] but even these are only effective if they are able to transport fish in a time-effective manner and do not injure the fish in the process. Research in freshwater fish passage is not nearly as extensive as research about the passage of migratory fish, especially salmon. A literature review of fish passage found that "Upstream and downstream fish passage for riverine fish species has not been studied as extensively as it has for anadromous species."[21] Although the effects of dams may be less obvious in freshwater fish populations than migratory fish populations, developing tools to protect these fish is still important to maintaining their healthy presence in the ecosystem.



A fish lift

Conclusion

The hydropower industry must significantly revamp its fish passage technologies before hydropower can be considered a green power source. Along with developing and building better fish passages, becoming environmentally friendly would require that each hydropower plant evaluate whether it's fish passages are

17 http://www.kleinschmidtgroup.com/service-areas/fish-passage-and-protection-services/fish-barrier-systems-design/
18 https://www.challenge.gov/challenge/downstream-fish-passage-at-tall-dams/
19 http://www.scientificamerican.com/article/upstream-battle-fishes-shun-modern-dam-passages-population-declines/
20 http://www.shwpc.com/fishlift.html
21 http://www.ceaa.gc.ca/050/documents_staticpost/cearref_2996/166-04.pdf

suitable for the dam's unique environmental conditions. More centralized coordination among dams along the same river needs also be implemented to make sure that the cumulative effect of all of a river's dams is not devastating to any species. Other environmental impacts of dams, including silting of riverbeds and changes to the temperature, nutrient content, and oxygen concentration of water must also taken into consideration. Though occasional individual power plants may effectively balance power production and environmental concerns in their unique ecosystems, for hydropower to have a large future in an increasingly environmentally conscious world, it must leave a smaller ecological footprint - or finprint.

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