Dams and Their Effect on Fish Biodiversity and Population throughout the United States

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Table of Contents

Introduction

In 2014, the U.S. generated over 4 trillion kilowatthours of electricity. Of that, 6% was from hydroelectric power (EIA, 2015). To generate hydroelectricity, impoundments and reservoirs are needed to store and create an artificial flow of water. Consequently, these dams and man-made lakes alter the natural landscape, while hindering a variety of species such as diadromous fish that rely on unimpaired waterways to travel from rivers to oceans. Dams have had such a detrimental effect on some aquatic life that they are believed to be extinct. Thus, this report aims to study how dams and aquatic species population are correlated. ArcGIS is the principle method of conducting this analysis, although other tools are referenced.

Grand Coulee Dam Photo (From Wikipedia)

In Elizabeth Kolbert's Pulitzer Prize winning book, *The Sixth Extinction*, the history of how extinction became a recognized phenomenon is succinctly described. Before Walter and Luis Alvarezes' June 1980 paper was published, "Extraterrestrial Cause for the Cretaceous Tertiary Extinction," the scientific community did not believe mass, catastrophic extinctions occurred. Two centuries before that paper was published, the idea that animals could go extinct seemed fictional. Now, it is quite clear humanity has led the world into a new era dubbed the "Anthropocene," where the rate of extinction is at least 1,000 times higher than the background extinction rate (WWF, 2015). Humans have therefore thrown the world off equilibrium because of a lack of understanding on how to balance human needs with the environment. Similar to how the idea of extinction has recently developed, so too has the idea of ecosystem services, and this report considers not only species that have gone extinct, but also those that are currently valued.

Methods and Data

ArcMap 10.3 was the GIS software used for creating the maps and conducting statistical analysis for this report. Location, construction dates of dams, and shapefiles were from the National Inventory of Dams (NID), publicly available on the Army Corps of Engineers website. The 2014 Review of Ocean Salmon Fisheries, Appendix B was the source of salmon population data. The 2010 National Fish Habitat Action Plan provided the shapefile to create a spatial distribution of habitat degradation risk. The organization Fishes of Texas contained a temporal video of phantom shiner sightings.

Analysis and Discussion

HISTORY OF DAMS IN THE U.S.

A history of dams was explored to visualize the spread of dams in the contiguous U.S. As shown in Figure 1, the earliest dam data recorded was 1640. These dams were earthen, not concrete dams, and all were under 40 feet in height. These dams may have been created by the Spanish or Native Americans, for the English had not even settled Georgia until 1670. In Figure 2, the construction of larger dams is seen throughout the U.S. up until 1900. It was during the 20th century that the majority of dams were constructed, as the Bureau of Reclamation and Army Corps of

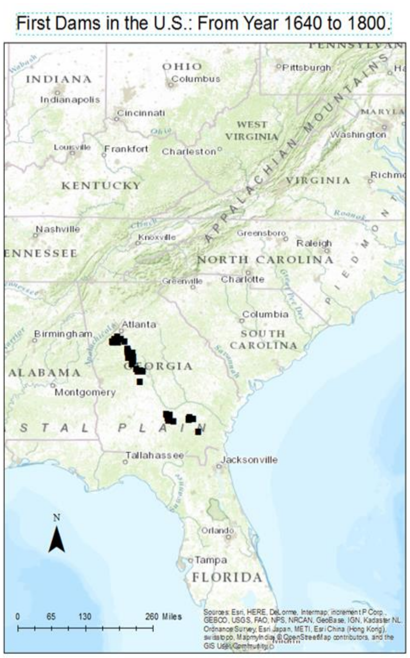


Figure 1: First Dams of the U.S.

Figure 3: Dams completed from 1800 to 1900

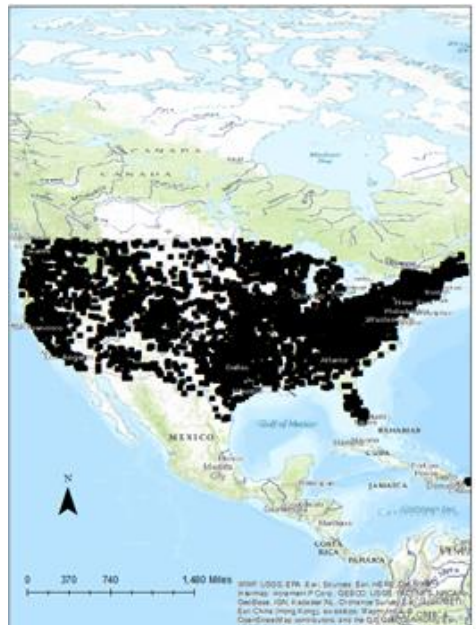


Figure 2: Dams in the U.S. Presently.

Engineers competed to build reservoirs and sources of hydropower. This significant increase is demonstrated in Figure 3, where the total dam count reached over 79,000. It is important to mention that this map includes relatively small dams, and that each dam must meet at least one of the criteria set by the Army Corps of Engineers:

1) High hazard classification - loss of one human life is likely if the dam fails,

2) Significant hazard classification - possible loss of human life and likely significant property or environmental destruction,

3) Equal or exceed 25 feet in height and exceed 15 acre-feet in storage,

4) Equal or exceed 50 acre-feet storage and exceed 6 feet in height.

To view the locations of dams and accompanying reservoirs with a capacity of 100,000 acre-feet and more, where the largest circles represent a capacity up to 9.7 billion acre-feet, reference Figure 4. Note that some reservoirs, such as Lake Superior, MI and Lake Okeechobee, FL were considered natural lakes until dams were constructed adjacent to them. Therefore the storage capacity of some reservoirs existed naturally.

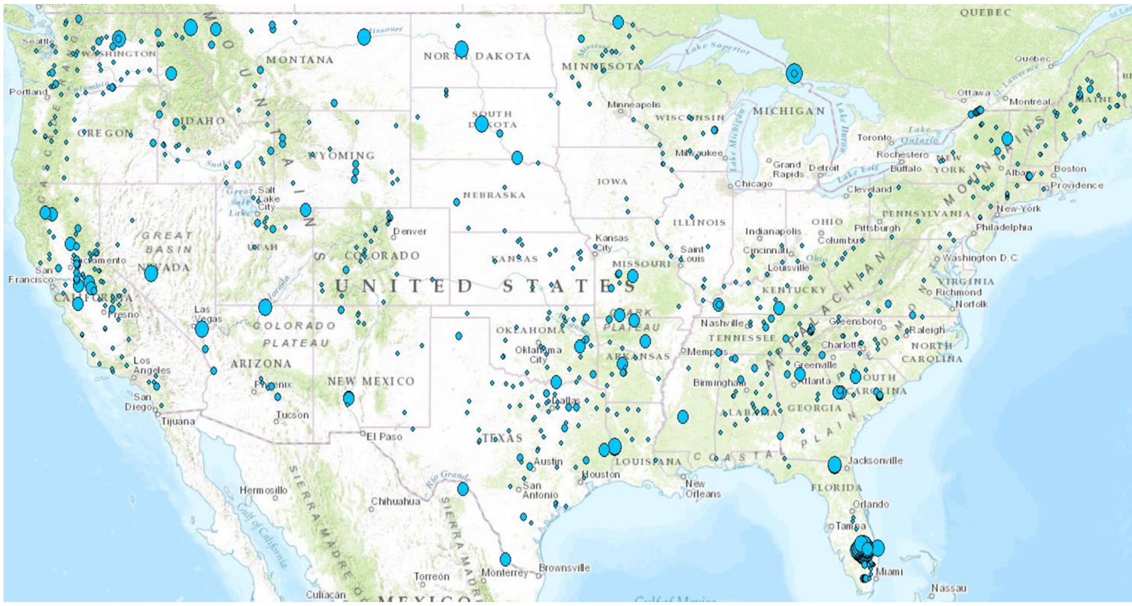


Figure 4: Dam reservoirs in the U.S. ranging from 100,000 acre feet to 9.7 billion acre-feet of normal storage.

CASE STUDY ON CALIFORNIAN CHINOOK SALMON

Nearly all rivers in the U.S. are impounded, which has had an impact on aquatic habitats. As early as 1870, it was found that dam construction was the principal cause of migratory fish extinction in Maine (Hall et al, 2011). Thus, a case study was started to determine the effect of dams on the population of the Sacramento River Chinook salmon. Referencing the Pacific Fishery Management Council for population data, the average adult population size within the natural areas of the Sacramento River (excluding hatcheries) was 151,286 between the years 1971-1975. The dams on the Sacramento River south of Shasta Lake shown in Figure 5 are the following: Shasta dam completed in 1945, Keswick dam (1949) and Red Bluff Diversion Dam (also known as a dike, 1964). Therefore the population data was taken after all the dams were constructed, and a gradual decline in salmon population was expected. However, the data shows a drop in population up until 1995 reaching an average adult population of 129,587, and then a sharp increase up until 2002, reaching 682,695 adults. This data proves that salmon can survive and thrive in rivers impounded by dams. It's important to note that about 160 miles of the Sacramento River south the Red Bluff Diversion is unimpeded, including the entrance to the San Pablo Bay, which is essential for anadromous fish that migrate between the ocean and freshwater.

Although the salmon are able to do well, the habitat conditions are not ideal. From 2003 to 2009, the salmon population plummeted to only 23,337 adults. Fortunately, the population rebounded to about 167,000 adults but was largely due to the influx of salmon from hatcheries which amounted to about 270,000 adults between the years 2012 to 2014. In fact, between 50 percent and 90 percent of the Sacramento River's chinooks are born in hatcheries depending on the health of the wild population (Tucker, 2008). Many of these salmon do not survive during their journey to and from the ocean, explaining the lower count. Furthermore, Shasta dam

Figure 5: Dams on Sacramento River from Shasta Lake to San Pablo Bay.

was the main detrimental factor to the salmon survival rate: “Last year, officials estimate that only about 5 percent of the winter-run Chinook that hatched in the Sacramento River below Shasta Dam survived long enough to migrate to sea. They died because water releases from Shasta flowed out warmer than federal models had predicted” (Sabalow, 2015).

HABITAT DEGRADATION RISK AND RELATION TO DAMS

Based on the salmon case study, further research was done on whether dams increase habitat degradation risk. Using the 2010 National Fish Habitat Action Plan, the Habitat Condition Index (HCI) score was spatially mapped in ArcMap, shown in Figure 6, where the orange regions correspond with high risk, while green regions correspond with low risk. The dams shown in Figure 3 are superimposed on Figure 6, showing how

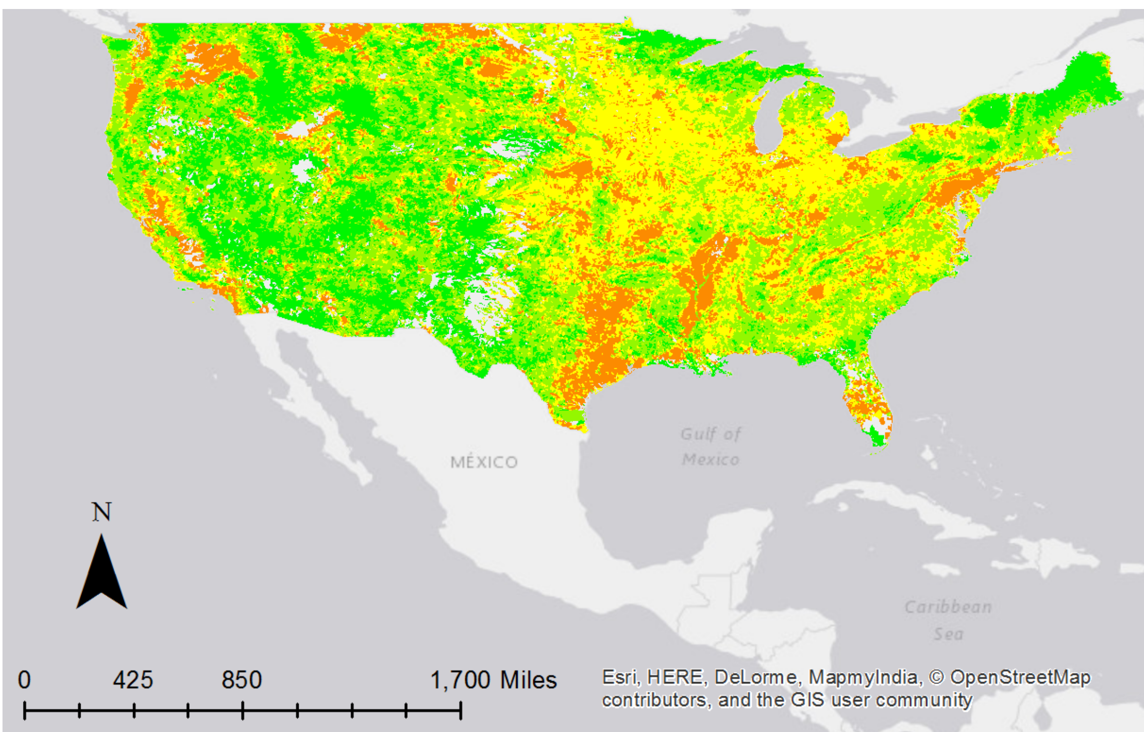


Figure 6: Habitat Risk Degradation, Green for Low Risk, Orange for High Risk.

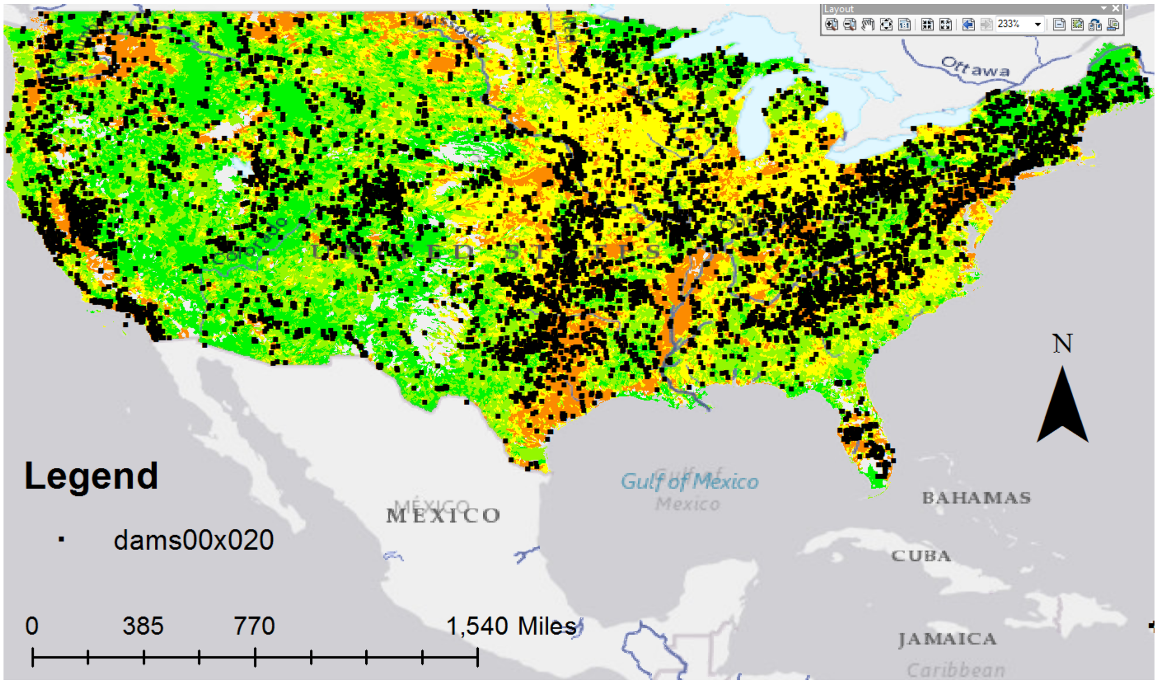
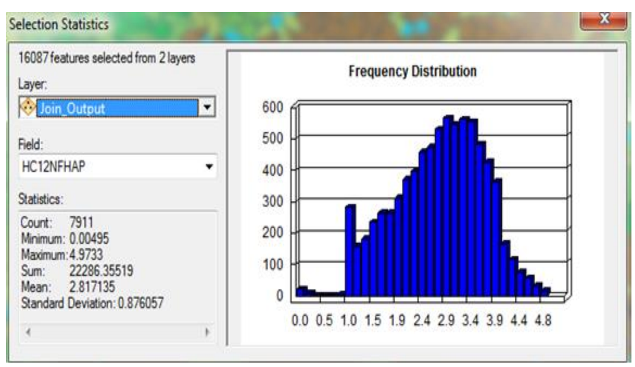


Figure 7: Dam location with respect to habitat degradation risk.

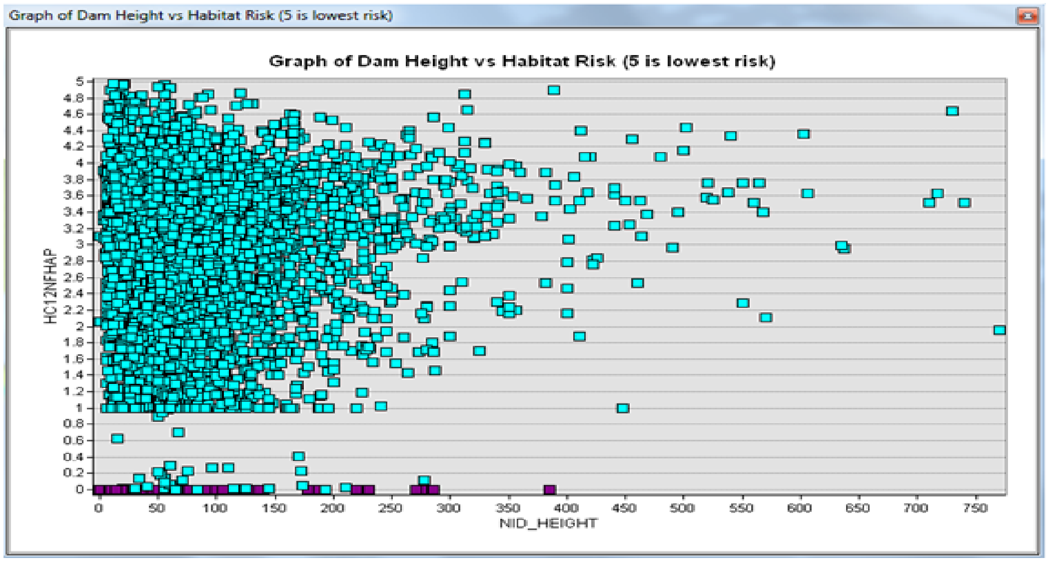
high concentrations of dams in California, Texas, and other states are adjacent to regions of high habitat degradation risk (Figure 7). Statistical analysis was run to determine whether a clear correlation exists between the size of a dam, in terms of dam height, and habitat risk. Table 1 depicts how habitat risk is distributed similar to a bell curve, were the average habitat faces moderate risk. By spatially joining the dam data with the habitat risk data, Table 2 shows that massive dams higher than 300 feet can be located on subwatersheds (HUC12) and be associated with both low and high risk. Considering that dams affect streams, the detrimental effect may be felt outside of the respective subwatershed as streams flowing

Table 1: Frequency of each segment of risk, 0 is very high risk, 5 very high risk.



from dams can pass through numerous catchments. This assumption appears to be supported in Figure 8, where the area surrounding the Sacramento River is zoomed in.

Table 2: Scatter plot of Dam height compared to Habitat Risk.



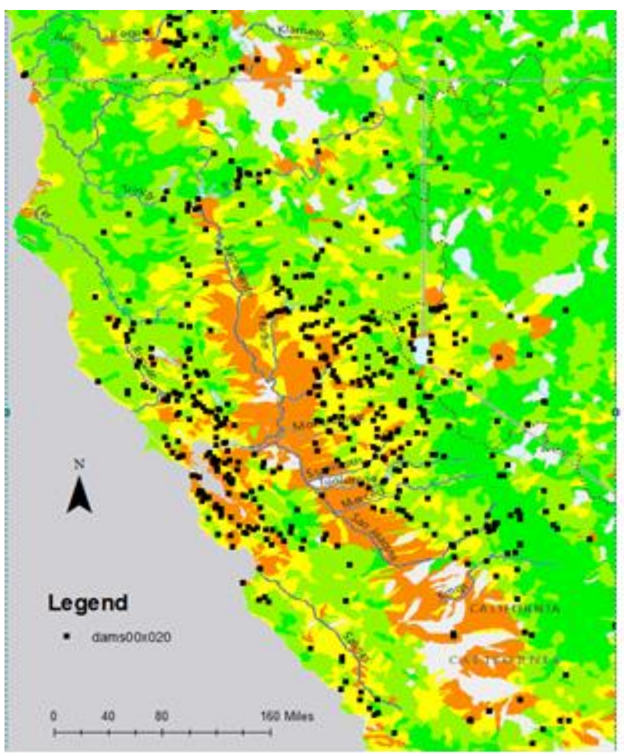


Figure 8: Dams surrounding Sacramento River, CA.

FISH EXTINCTION AND RELATION TO DAMS

The phantom shiner, or *Notropis orca*, was a fish that swam along the Rio Grande River on the south border of Texas. It's currently believed to be extinct. Figure 9 is a picture of unverified sightings of this minnow from the Fishes of Texas website. According to the site and research by Bestgen and Platania (1990), the endemic species "may have been prevented from migrating to secure areas as a result of river desiccation, extreme distance, or habitat desiccation due to construction of dams and were unable to survive in reservoirs." A considerable amount of research has been conducted on how dams fragment and alter ecosystems, and species unable to adapt to the new conditions are the highest risk for extinction.

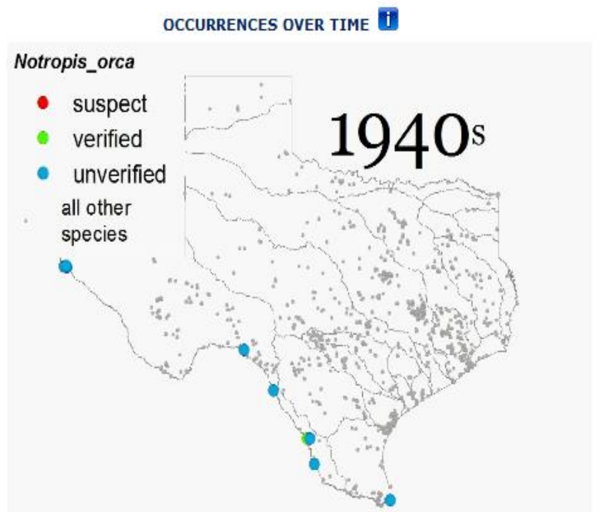


Figure 9: Unverified sightings of Phantom Shiner up to 1940s.

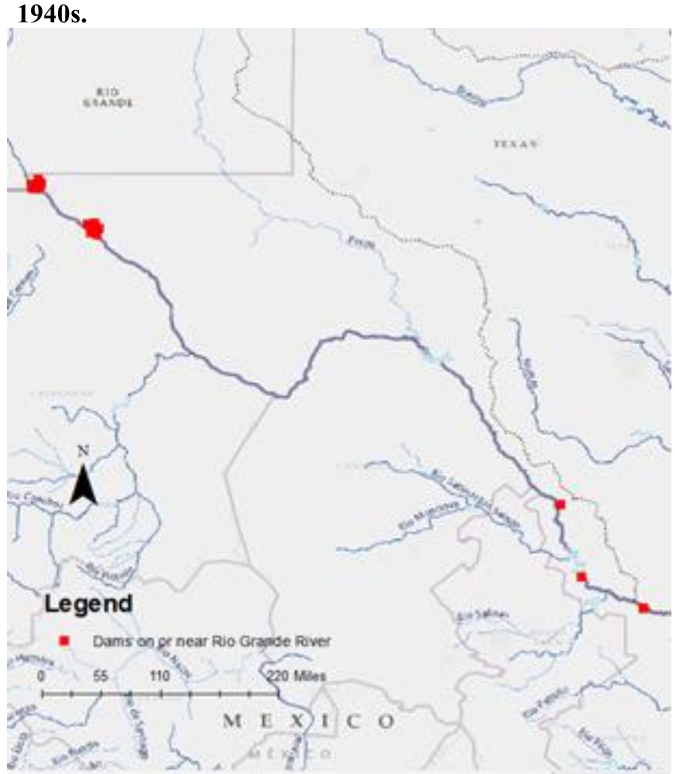


Figure 10: Location of dams near and on Rio Grande River, TX.

Conclusions

It is indubitable that infrastructure development within the U.S. has reshaped the natural landscape. Consequently, diadromous fish species are endangered or extinct as the changes brought upon them were too rapid for evolution. Dams and reservoirs may not be the only cause, but they are a major factor. Deconstructing dams is seen as a solution for certain areas, but is not cost-effective for the larger dams. Therefore, impoundment managers are left with the responsibility of optimizing human demand for water with environmental needs. Discharging water to mimic natural flows, constructing fish ladders, and providing alternative modes of transport around the dam for fish are examples of positive human impact despite current conditions. Furthermore, as dams are inspected, decommissioned, and modified, more informed decisions on mitigating habitat degradation can be made.

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