AMERICAN RIVERS

THE ECOLOGY OF DAM REMOVAL

A Summary of Benefits and Impacts

American Rivers

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INTRODUCTION

Rivers and their restoration are complex, and any effort to rehabilitate a river system needs to be based on a sound understanding of the ecological benefits and drawbacks of a proposed restoration plan. Over the past three decades, the scientific community has advanced our understanding of rivers and helped us to realize the significant negative impacts that dams have on river systems. Dams disrupt a river's natural course and flow, alter water temperatures in the stream, redirect river channels, transform floodplains, and disrupt river continuity.[1] These dramatic changes often reduce and transform the biological make-up of rivers, isolating populations of fish and wildlife and their habitats within a river.

While there is a need for more specialized research on the ecological impacts of dams and dam removal, several studies indicate that dam removal can be a highly effective river restoration tool to reverse these impacts and restore rivers. Angela T. Bednarek, a Ph.D. candidate at the University of Pennsylvania recently conducted a comprehensive review of the short- and long-term ecological impacts of dam removal. Bednarek conducted a literature search to identify and review all available published (and many unpublished) studies on dam removal to determine if and how dam removal can be effective in improving water quality and restoring fish and wildlife habitat in and around a river. Her study focused on numerous ecological measures that are critical to assessing the positive and negative impacts of dam removal both from short- and long-term perspectives, including:

- Flow;
- Shift from reservoir to free-flowing river;
- Water quality (e.g., temperature and supersaturation);
- Sediment release and transport; and
- Connectivity (e.g., migration of fish and other organisms).

While there are some limited short-term ecological consequences of dam removal, Bednarek's study found that the long-term ecological benefits of dam removal—as measured in improved water quality, sediment transport, and native resident and migratory species recovery—demonstrates that dam removal can be an effective long-term river restoration tool.

This paper summarizes Bednarek's findings and comments on Bednarek's call for additional research to further the scientific community's knowledge of the ecological impacts of dam removal. The paper is organized into five sections: (1) reestablishment of a natural flow regime; (2) transformation from reservoir to river system; (3) change in river temperatures and oxygen levels; (4) sediment release and transport; and (5) migration of fish and other organisms. Bednarek's paper was published in the journal, *Environmental Management*, in spring 2001 (Bednarek, Angela. 2001. "Undamming Rivers: A Review of the Ecological Impacts of Dam Removal." *Environmental Management* 27(6):803-814.). To obtain a copy, please contact the *Rivers Unplugged* campaign at *American Rivers* by calling (202) 347-7550 or emailing RiversUnplugged@amrivers.org.

[1] Petts 1984, Yeager 1994, Ligon and others 1995, Ward and Stanford 1995, Stanford and others 1996, Poff and others 1997, Born and others 1998

REESTABLISHMENT OF A NATURAL FLOW REGIME

A river's physical and biological characteristics are determined in large part by its flow regime. A river's flow regime refers to the range in magnitude, regularity, and frequency of water transport down a river channel and over a set period (i.e., seasonal, year-round, life-time). Natural river flows fluctuate according to the season, often with large spring flows corresponding to spring rains or snowmelt, and low summer flows corresponding to warm, dry summer weather.[2] Because a river ecosystem is dynamic, a river can support a wide diversity of species, all of which have evolved to live in a river's variable flow. On many rivers, large floods inundate regions alongside rivers, carrying organisms, inorganic and organic debris, and nutrients into the river channel.[3] Additionally, smaller flows serve to transport and redistribute sediments and organisms within the stream.

Ecological Consequences of Dams

Dams dramatically alter a river's flow regime by blocking a river's passage, storing water in both large and small artificial reservoirs,[4] and disrupting the cycles that many aquatic organisms depend upon. Bednarek's paper points out that in rivers that have a regulated flow, dam releases are often timed to meet human demands for water supply, navigation, power production, and recreation,[5] disregarding the needs of the stream's aquatic organisms. Consequently, altered fluctuation in flow caused by dams can result in an aquatic community limited to a few generalist species that are able to withstand the altered flow conditions of the river.

In many cases, dams that produce hydroelectricity regulate rivers with an unnaturally high range in flow.[6] For example, the Tennessee Valley Authority (TVA) regulates the Ocoee River in the southeastern United States for white-water recreation, while at other times of the year TVA drains and redirects the river for power generation.[7] While flow fluctuations on the Ocoee River are seasonal, in many other cases, the flow regime on rivers is altered daily or hourly. Regulated seasonal, daily, and hourly flow management programs are damaging to river ecosystems, physically scouring aquatic organisms and reducing populations of river fauna.[8] Withholding water from the streambed for long or frequent periods further reduces river health by inhibiting riparian vegetation growth and stranding insects, fish, and bird nests.[9]

Ecological Benefits of Dam Removal

Bednarek's paper indicates that when natural flow fluctuations are restored to a river, biodiversity and population densities of native aquatic organisms increase. For example, Florida's Dead Lake Dam on the Chipola River regulated the river to a more constant flow when

[2] Junk and others 1989, Heiler and others 1995, Poff and others 1997
[3] Junk and others 1989, Heiler and others 1995, Stanford and others 1996
[4] Poff and others 1997
[5] Malmqvist and Englund 1996, Collier and others 1996
[6] Gillilan and Brown 1997
[7] Devine 1995
[8] Camargo and Voelz 1998
[9] Stanford and Hauer 1991, Nilsson and Dynesius 1994, Nilsson and others 1997

compared to pre-impoundment flow conditions. Once the dam was removed, fluctuations in the natural flow of the river increased, and the diversity of species nearly doubled from 34 to 61 aquatic species.[10] It is likely that the successful rebound of aquatic species diversity on the Chipola River is closely related to habitat restoration created by restoring the natural flows to the river. Following dam removal and during the naturally restored low flow periods of the river; vegetation growth (i.e., alligatorweed) recovered in the river.[11] This increase in vegetation improved the spawning habitat for largemouth bass and other native fish to the area, and may have been a factor in boosting fish populations.[12] In another example, officials released a large flood from the Glen Canyon Dam on the Colorado River in 1996, one of the goals being to restore habitat for aquatic species, which historically have depended upon the rivers naturally occurring and periodic high flows. Studies following the release indicated that some restoration of beaches and riverine habitat occurred.[13]

According to Bednarek's report, wetlands adjacent to rivers also benefit from dam removal. Studies to remove the Rodman Dam in Florida stressed the need to restore natural flows, which serve to inundate terrestrial areas, such as flood plains. If the dam were to be removed, riparian areas would likely flood more frequently, promoting riparian plant growth, revitalizing inland wetlands, and creating small ephemeral ponds which serve as nurseries for aquatic species. Furthermore, the rise in riparian vegetation would create new habitat and food for a wide range of species, including Florida's endangered panthers and black bears.[14]

Coastal rivers can also be positively impacted by dam removal. Many dams prevent ocean tidal surges and sea-run fish from moving upstream; most migratory fish rely on these same tidal surges to transport themselves from estuaries and coastal regions into upstream spawning habitat.[15] Removing dams on coastal rivers can dramatically enhance reproductive rates for aquatic organisms that depend on the movement of tides to help them to return to coastal breeding areas. For example, the removal of the Edwards Dam on the Kennebec River in Maine provided coastal fish populations access to previously impounded upstream habitats, including head of tide habitat. Now that the dam has been removed, as expected, regional populations of striped bass, Atlantic and shortnosed sturgeon, smelt, American shad, and blueback herring have increased, in some cases significantly, due to the re-establishment of the natural interaction between the river and the sea.[16]

TRANSFORMATION FROM RESERVOIR TO RIVER SYSTEM

Ecological Consequences of Dams

The majority of dams transform part of a river into lake-like habitat by creating impoundments of varying size. The slower water flow and larger surface area created by dams can alter the

[10] Hill and others 1993
[11] Hill and others 1993, Estes and others 1993
[12] Hill and others 1993
[13] Collier and others 1996, Collier and others 1997
[14] Kaufman 1992
[15] Ouellet and Dodson 1985, Dadswell 1996. See also the discussion in the below section, Migration of Fish and Other Organisims.
[16] Dadswell 1996

species composition of organisms in the river, favoring slower-moving aquatic species that are better adapted to lake-like bodies of water. For example, along the dammed Snake River in the Pacific Northwest, slow-moving, reservoir habitat has led to an increase in fish species that prey on salmon and steelhead populations, exacerbating the continual decline of these populations along the Snake River.[17]

Ecological Benefits of Dam Removal

According to Bednarek's paper, dam removal can enable the return of native species by restoring the pre-dam, riverine habitats on which native species depend. Following the removal of the Woolen Mills Dam in Wisconsin, high densities of non-native common carp declined, while populations of native species such as smallmouth bass increased.[18] In other parts of the country, dam removal often displaces warm-water species that prefer a lake-like environment, while promoting the recovery of fish populations that prefer colder-water rivers, such as salmon, trout, shad, river herring, stripped bass, sturgeon, and alewife. Other studies on the west coast suggest that dam removal may benefit native aquatic and terrestrial species as well. The removal of two dams on Washington's Elwha River are expected to restore over 715 acres of terrestrial vegetation, which will improve elk migration corridors and their over-wintering habitats.[19]

Ecological Impacts of Dam Removal

It is important to note that in some dam removal cases, the diversity of certain organisms that prefer lake-like conditions may decline. Wet meadow grasses replaced species of cattail and sedge when the Fulton Dam on the Yahara River in Wisconsin came down.[20] Consequently, duck and muskrat populations that relied on cattail and sedge for habitat were negatively impacted by the removal of the Fulton Dam. The Fulton Dam removal, however, did not have a negative impact on many other native species to the region, such as turtles, amphibians, mink, raccoon, and skunk, all of which continued to thrive in the area following dam removal. In other words, while dam removal may negatively impact some species, in many cases, dam removal reestablishes native ecosystems and supports the recovery of native aquatic organisms.

CHANGE IN RIVER TEMPERATURES & OXYGEN LEVELS

Ecological Consequences of Dams

Many dams convert fast-moving rivers into slower-moving lake-like habitats with relatively large surface areas. Because of the increase in water depth and decrease in flow velocity created by a dam, a reservoir may separate into several layers of water with varying temperatures, a process known as temperature stratification. A reservoir's top layer of water (epilimnion) will warm and decrease in density, while cooler, denser water will sink to the bottom layer (hypolimnion) of the reservoir. Because many reservoirs are deep, the bottom and top layers

[17] Wik 1995
[18] Staggs and others 1995, Kanehl and others 1997
[19] Department of the Interior 1995
[20] American Society of Civil Engineers 1997

often do not mix well, inhibiting gas transfer between the highly oxygenated surface layers and the poorly oxygenated bottom layer.[21]

Bednarek's paper points out that many dams draw water from the cool bottom layer of the reservoir, a process that artificially decreases the temperature of the water that flows out from underneath the dam (tail waters).[22] While many fish prefer cool water, tailwater releases are often devoid of sufficient oxygen to support traditional cold-water fish. In addition, changes in temperature within and downstream of the reservoir can affect species composition, diminishing population densities of some native migrating species. For example, certain fish species have evolved to swim in cool water. If water temperatures warm considerably due to the presence of a dam, these fish populations may be unable to reach upstream spawning habitats because of the inhospitably warm water temperatures created by the dam. In other words, a dam may alter water temperatures in such a way as to create a thermal block to fish migration.[23]

Ecological Benefits of Dam Removal

While dams may alter a river's temperature, dam removal can restore a river's natural water temperature range. One study of the Salling Dam on the AuSable River in Michigan estimated that removal of the dam would reduce water temperatures in the former impoundment and downstream by approximately 3° Celsius, thereby restoring natural water temperatures to the river.[24] Unfortunately, there have been few studies measuring the effects of dam removal on water temperature. In making any dam removal decision, it is important that decision-makers properly account for the changes in temperature that a release from the reservoir could impose on the river.

Ecological Impacts of Dam Removal

Bednarek's paper indicates that dam removal can also have a negative short-term impact on a stream's temperature and oxygen levels. When a dam is removed, supersaturation—the process by which velocity and air pressure are increased above natural conditions in a stream—can occur. Supersaturation can negatively impact downstream organisms. For instance, gas-bubble disease in fish (a disease which can result in fish death due to gas emboli in the gills and tissues) can occur when a reservoir is drawn down to quickly.[25] When the Little Goose Dam on the Snake River was drawn down in 1992, supersaturation of dissolved gas occurred in the water, turbidity levels increased, and many reservoir fish and insects perished. Fortunately, fish losses associated with this draw down were short-term with minimal impacts on overall populations.[26] Slowly drawing down a reservoir, prior to dam removal, can significantly lessen the impact of supersaturation on downstream species.

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[21] Yeager 1994
[22] Yeager 1994
[23] Gillilan and Brown 1997
[24] Pawloski and Cook 1993
[25] Weitkamp and Katz 1980, Wik 1995
[26] Wik 1995

SEDIMENT RELEASE AND TRANSPORT

Sediment transport in a river is vital to riparian and riverine habitats and species. Most free flowing rivers are characterized by wide fluctuations in flow, which affects sediment transport and creates unique and diverse habitats for species. Large flows serve to erode small, nutrient-rich sediments from a river and its shoreline, depositing this material downstream and in rich coastal breeding grounds such as estuaries. These same flows transport and redistribute larger sediments and boulders, creating new and more diverse habitat for aquatic species. Studies have shown that variations in sediment sizes transported by a river promote species diversity and aquatic health by increasing the variety of habitats for feeding, spawning, and breeding. Some fish species, for example, require varying habitats that change seasonally and throughout their lifetime. During the high river flows typical of summer, the adults of certain species feed in riffles with small cobbles.[27] In wintertime, however, these adults inhabit small pools with slower moving current. Additional studies have also shown that salmonid fish rely on varying sediment types for spawning.[28]

Ecological Consequences of Dams

As indicated in Bednarek's paper, dams block the movement of sediment within a river, depositing much of the material behind the dam and altering the river's habitat.[29] Sediment accumulation behind a dam restricts the amount and types of sediment that reach areas downstream, as well as the habitat available within the reservoir. Furthermore, because dams restrict the flow of rivers, dammed rivers often can no longer distribute large material such as boulders and cobble downstream. Once a dammed river has lost the ability to transport large materials, the streambed begins to rise, exacerbating habitat loss within the reservoir.[30] In addition to rising streambeds, smaller material (i.e., sand and silt) often settles close to the dam and slowly fills the reservoir, a process that often severely limits hydropower operations, water storage, and flood control.[31]

Dams reduce the amount of sediments deposited downstream, creating an adverse effect on downstream aquatic species and their habitats.[32] Because dams force sediments to settle to the bottom of the streambed, the waters that eventually pass through a dam are "sediment starved" and are also known as "clear-water releases". Downstream of a dam, sediment-starved rivers often regain sediments lost behind a dam by eroding deeper into the river channel and away at the stream banks.[33] Consequently, the river channel may become coarse, encouraging stream bank erosion and the disappearance of riffles.[34] By limiting access to water, dams can also exacerbate channel scouring, a process which may lower groundwater tables and negatively impact riparian habitats.[35] Together, stream-bank erosion and channel incision can render the

[27] Rabeni and Jacobson 1993
[28] Kondolf 1997
[29] Kondolf 1997, Wood and Armitage 1997
[30] Petts 1984, Fan and Springer 1990
[31] Petts 1984
[32] Church 1995, Kondolf 1997
[33] Kondolf 1997
[34] Dietrich and others 1989, Quinn and Hickey 1990, Sear 1995, Kondolf 1997
[35] Gillilan and Brown 1997

remaining river habitat inhospitable for many organisms, altering the community of species that live in the stream.[36] Finally, because rivers transport much of the sediments that create coastal habitats, impounding rivers and their sediments can exacerbate the loss of shoreline habitats that depend on continued sediment transport.

Ecological Benefits of Dam Removal

Dam removal often redistributes sediments trapped behind a dam, restoring the river and its riverine habitats to pre-dam conditions, according to Bednarek. Following the removal of the Woolen Mills Dam on the Milwaukee River in Wisconsin, the percent of rocky substrate compared to silt and mud found in the former impoundment significantly increased.[37] In addition, once the dam was removed, native fish such as smallmouth bass increased in number, a positive trend that can be attributed to the reintroduction of larger and more course sediments to the river habitat.[38] As shown in the Woolen Mills case, dam removal allows for the freer movement of sediments (i.e., sand, gravel, and cobbles), and can restore river sedimentation patterns in the reservoir basin and downstream from the dam.

Following dam removal, gravel and cobble upstream from the dam (i.e., the old reservoir basin), may become re-exposed, as rocky materials that were previously covered under fine sediments are washed downstream. Re-exposing gravel or cobble in the riverbed often provides new colonization habitat for aquatic insects and revitalized spawning habitat for fish. For example, the removal of the Stronach Dam on the Pine River in Michigan is expected to erode sand that has covered nearly 4 km of upstream river habitat, thereby re-exposing the natural gravel/cobble substrate that native trout strongly prefer.[39] In the case of the Edwards Dam on the Kennebec, approximately 18 miles of riverine habitat was recovered. Dam removal restored spawning habitat above the dam for ten species of sea-run fish, exposed six separate runs of reestablished riffle/pool sequences, varying speeds in river current, and a varied substrate.[40]

Dam removal can play a key role in restoring sediments to coastal beaches as well. The Elwha Dam and Glines Canyon Dam in Washington State have trapped many of the fine sediments that historically accumulated along shoreline beaches, resulting in beach erosion.[41] Non-native species such as kelp and barnacles have also benefited from the obstruction of sediments behind these dams. These two species have grown at alarming rates and have overcome native species in the Strait of Juan de Fuca. Sediment obstruction caused by these dams has also exacerbated the loss of critical estuaries, the nurseries for many fish and shrimp.[42] Studies predict that removal of the two Elwha River dams is likely to restore the natural sediment movement, thus reversing the negative impacts of coastal sediment loss. Both of these dams on the Elwha River are scheduled for removal, pending funds to be appropriated by Congress.

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[36] Quinn and Hickey 1990, Staggs and others 1995, Kanehl and others 1997
[37] Kanehl and others 1997
[38] Nelson and Pajak 1990
[39] D. Hayes and K. Klomp, personal communication
[40] Stone and Webster 1995, Dadswell 1996
[41] Department of the Interior 1995
[42] Department of the Interior 1995

Ecological Impacts of Dam Removal

One concern of the dam removal process is the short-term increase in turbidity and water quality problems that may occur if sediment accumulation is not addressed properly. Bednarek's paper suggests that many dams accumulate fine silt and sand sediments in their impoundments.[43] Following dam removal, much of this sediment may become re-suspended into the free-flowing river (whether or not the sediment becomes mobilized depends on the conditions of removal and the nature of the substrate).[44] This short-term influx of sediments into the stream flow can damage spawning grounds,[45] and negatively impact water, habitat,[46] and food quality.[47] If the sediments contain toxics, impacts from dam removal can be more significant. Contaminants, which can attach well to smaller sediments, can pose a threat to downstream habitats and fish and wildlife.[48] For example, when the Fort Edwards Dam on the Hudson River in New York was removed in 1973, sediments containing PCB (polychlorinated biphenyl) were released downstream.[49] With careful studies and planning, scientists and decision-makers will be able to mitigate for the potential downstream effects of contaminated sediments caused by dam removal.

Fortunately, most commonly re-suspended sediment from the dam removal process has had a temporary effect on rivers. Several studies show that following dam removal, sediments have successfully been flushed out of river channels and natural sediment transport conditions have resumed.[50] Within one week, much of the silt and sediment that had been stored behind the Grangeville and Lewiston Dams on Idaho's Clearwater River was washed downstream, despite the fact that the Lewiston Dam's reservoir was completely filled with sediment prior to removal.[51] In other cases, flushing sediments downstream is a slower process. It is estimated that it may take 50-80 years to flush stored sediments downstream following the removal of the Newaygo Dam on the Muskegon River in Michigan.[52] Timing dam removals carefully can be one of the best tools to mitigate for the negative short-term impacts of dam removal. The Grangeville Dam in Idaho was removed before the spring run-off in order to limit the negative impact of stored sediments moving downstream.[53] Gradually drawing down the reservoir, trapping sediments in screens, and channel dredging of the reservoir sediments are other techniques used to reduce the short-term impacts of sediments on downstream habitats following dam removal.[54]

[43] Kondolf 1997
[44] Doeg and Koehn 1994, Born and others 1996
[45] Bogan 1993, Born and others 1996
[46] Newcombe and MacDonald 1991, Wood and Armitage 1997, Doeg and Koehn 1994
[47] Wood and Armitage 1997
[48] Stone and Droppo 1992, Wood and Armitage 1997
[49] Shuman 1995, Chatterjee 1997
[50] Winter 1990, Kanehl and others 1997
[51] Winter 1990
[52] Simons and Simons 1991
[53] Winter 1990
[54] American Society of Civil Engineers 1997

MIGRATION OF FISH AND OTHER ORGANISMS

Ecological Consequences of Dams

A dam disrupts river connectivity and can block passage both up- and downstream for migrating fish and other wildlife. This is the case for sea-run (anadromous and catadromous) fish that migrate between salt and fresh water, as well as for residential fish that move up and down a river to find suitable spawning, rearing and foraging habitat. In addition, dams fragment the river corridor by isolating populations and habitats, altering the river environment both physically and thermally, and disturbing the interface between land, freshwater, and coastal ecosystems.[55] This combined negative impact of dams on aquatic species can adversely impact reproduction.

Ecological Benefits of Dam Removal

Reproductive success, which often depends on appropriate timing for reaching spawning or breeding habits, can be improved by the removal of dams that prevent the migration of aquatic organisms, according to Bednarek's report. Furthermore, dam removal decreases the risk of mortality for organisms that would otherwise have to pass through dams. For instance, many dams across the United States have no fish passage structures; removal of these dams allow migratory and resident fish populations to gain access to habitats blocked off by dams.

On dams where fish passage structures have been installed, fish can be injured or killed when moving up fish ladders or being flushed through turbines.[56] Further, predation is often increased in the area below fish ladders where fish wait to move up the structure. Additionally, because fish passage structures cause delays in fish migration, removal of a dam will improve the odds of successful reproduction.[57] For example, delays in reproduction cause the American shad to reabsorb its gonads without releasing its eggs or sperm prior to returning to the ocean.[58] Removing dams will likely boost the recovery of American shad by eliminating the reproductive delays caused by dams. In addition, dam removal benefits many species of fish that cannot use fish passage. Small fish often encounter difficulty working their way over a fish passage designed for larger fish, while some fish, such as the Atlantic sturgeon, are so big they cannot rely on fish passage for transportation.[59]

Researchers believe that dam removal benefits non-migrating fish and other organisms as well. One study on the removal of the Woolen Mills Dam determined that darter populations likely increased due to improved habitat quality and access to new river regions created by dam removal.[60] In addition, smallmouth bass gained access to optimum spawning conditions following the removal of the Woolen Mills Dam.[61]

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[55] Winston and others 1991, Chisholm and Aadland 1994, Dynesius and Nilsson 1994, Stanford and others 1996
[56] Travnicheck and others 1993
[57] Winter 1990, Drinkwater and Frank 1994, Wik 1995
[58] Dadswell 1996
[59] Dadswell 1996
[60] Staggs and others 1995, Kanehl and others 1997
[61] Staggs and others 1995

It is important to consider that on rivers with several dams, efforts to breach one dam may not significantly restore river continuity, due to the combined effect of other dams that continue to prevent fish migration.[62] For example, in 1963, the removal of the Washington Water Power Dam on the Clearwater River in Idaho helped to improve Chinook salmon habitat. Unfortunately, downstream dams on the Snake and Columbia Rivers continue to thwart the species ability to return to the sea.[63] In promoting fish migration, rivers often need to be restored as entire units and not as fragmented pieces.

Ecological Impacts of Dam Removal

Removing a dam on a contaminated river can have a negative impact on the stream community. In some cases, dams create a useful barrier between fish populations up- and downstream of a dam. For example, if fish populations are contaminated with toxins downstream of a dam, the dam may prevent these same populations from migrating upstream and contaminating fish populations above the dam. Additionally, dams can prevent the invasion of exotic species either above or below the structure. Many scientists are currently debating this issue.

CONCLUSIONS

Bednarek's survey indicates that dam removal can have significant ecological benefits, including the return of a more naturalized flow, temperature regime, and sediment transport to the river system. Studies have also shown that dam removals promote the rehabilitation of native species following dam removal, while providing for the migration or movement of species within a river. In addition, dam removal does not require a constant input of money and technology to maintain a functioning, healthy ecosystem, unlike alternatives such as fish passages and barges.

Though there are some negative ecological impacts associated with dam removal, Bednarek observes that most of these impacts have short-term effects on a river system. Furthermore, some of the short-term consequences associated with dam removal can be minimized through careful planning and timing of the removal process. Bednarek concludes that additional studies to determine the best approach to minimizing the short-term ecological impacts of dam removal are critical for decision-makers as they weigh the pros and cons of dam removal.

Any decision to remove a dam must include a careful examination of all the potential ecological impacts of dam removal, as well as the continued ecological impacts of a standing dam. Bednarek's findings—as well as more current studies, such as the dam removal study on Manatawny Creek currently being conducted by Dr. David Hart from the Academy of Natural Sciences—suggest that dam removal may be a sensible alternative for promoting the ecological health of a river ecosystem.

[62] Tyus 1992
[63] Shuman 1995

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