HEDONIC ANALYSIS OF DAM REMOVAL: EVIDENCE FROM A NATURAL EXPERIMENT USING MATCHING METHODS IN MAINE, USA

by

ELENA KRASOVSKAIA

(Under the Direction of Craig Landry)

ABSTRACT

Empirical evidence indicates that river proximity in Maine (USA) is a disamenity to residential property owners; a legacy of industrial activities created a significant impetus for damming and intensive commercial management of waterways. As a result, water quality deteriorated, aquatic populations plummeted, recreational fishing quality suffered, and river amenities were lost. With concern over sea-run fisheries and a significant decline of mills, interest in dam removal has piqued. Using home sales data on the Penobscot River in Maine, we estimate marginal willingness to pay (WTP) for river proximity before and after dam removal. The timing of sales encompasses two dam removals. Building upon earlier works, using difference-in-differences and matching methods, we find a negative effect of river proximity, that diminishes in a wake of dam removal, evidently implying improvements in river amenity effects following the removal.

INDEX WORDS: Hedonic property values, Matching methods, River restoration, Dam removal, Difference-in-Differences

HEDONIC ANALYSIS OF DAM REMOVAL: EVIDENCE FROM A NATURAL EXPERIMENT USING MATCHING METHODS IN MAINE, USA

by

ELENA KRASOVSKAIA

BS, Altai State University, Russia, 2015

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2021

HEDONIC ANALYSIS OF DAM REMOVAL: EVIDENCE FROM A NATURAL

EXPERIMENT USING MATCHING METHODS IN MAINE, USA

by

ELENA KRASOVSKAIA

Major Professor: Craig Landry
Committee: Susana Ferreira
Mateusz Filipski
Lynne Lewis

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
August 2021

DEDICATION

I dedicate my work to Joline Conine, Jeanne Ellen Heaton and Kelly McGiboney at Fuel Hot Yoga. Their endless kindness, love and guidance helped me to move forward through challenging times during my time at UGA.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my advisor, Dr. Craig Landry, for his continuous support and guidance throughout my time at UGA. I have learned a lot from Dr. Landry, and I am sincerely grateful for the research opportunities and experience I gained while working with him. I would also like to thank Dr. Gregory Colson for his valuable academic advice and inspiration; his passion and attitude to academia and teaching helped to better understand what a researcher I wish to become. Thank you to my committee members: Dr. Susana Ferreira, Dr. Mateusz Filipski, and Dr. Lynne Lewis, for their valuable feedback and comments which helped to improve this thesis. Thank you to my friends, Shweta Adhikari, Angela Blash, and Anna Perry for their support and encouragement during my master's studies.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION AND BACKGROUND

A river, that flows freely is a key resource for the world. Representing a fairly small percentage of Earth's surface, rivers are one of the most productive and diverse ecosystems on our planet (Opperman et al., 2015). Besides, about half of all existing fish species on Earth can be found in rivers, and the majority of people depend on food products that can only be grown using resources from free-flowing rivers (Opperman et al., 2015).

1.1. Dam Removal in the United States

During the 20th-century people dammed and regulated most of the world's rivers (Nilsson et al., 2005) for reasons such as electric power generation, flood control, water supply, reservoir recreation, navigational services, and more (Whitelaw and Macmullan, 2002; Magilligan et al., 2016; Lejon et al., 2009). The prolonged history of dam popularity led to the construction of hundreds of thousands of dams across the United States (USACE, 2018; Graf, 1993; Magilligan et al., 2016). Despite their benefits, however, dams also represent a physical barrier that intervenes natural river flow and comes at cost of ecosystem services provided by rivers.

The true number of US dams is unknown. Some studies suggest less than 100 000 dams (Magilligan et al., 2016; USACE, 2018), while others state that there are over 2 million dams across the US (Graf, 1993; Shuman, 1995). According to Lejon et al. (2009) and Blachly (2020), such controversy arises from fact that dams that are more than 15 meters in height are included in the National Inventory of Dams[1], which currently states that there are more than 90 000 dams

[1] https://nid.sec.usace.army.mil/

nation-wide. There is no existing record on the number of smaller dams and barriers, however, but once we account for them, we get the estimate of over 2 million.

The presence of dams often determines the combination of ecosystem services provided by a river (Blachly, 2020). Dams can increase water retention, reduce sediment transport, modify hydrography, interfere with plant and animal migration (Ward and Stanford, 1995; Jansson et al., 2000; Kingsford, 2000; Syvitski et al., 2005; Lejon et al., 2009), and negatively affect fish habitat (Hart and Poff, 2002). People can also be negatively affected by dams, due to poor water quality and water availability, lower aquatic productivity, and reduced control over invasive species (Nilsson et al., 2005; Lejon et al., 2009), which can potentially reduce their property value. Furthermore, ecological benefits from free-flowing rivers by themselves have received an increased recognition over the past years (Auerbach et al., 2014; Bednarek, 2001; Vermaat et al., 2016).

Lately, technological changes and evolving values have shifted trends in dam construction. Moreover, during the last couple of decades a considerable movement toward dam removals has started in the US (Magilligan et al., 2016; Grant and Lewis, 2015; Bellmore et al., 2016; Foley et al., 2017; Doyle et al., 2003) and worldwide (Lejon et al., 2009; Wang et al., 2014, World Commission on Dams, 2000). Even though dam removals have become increasingly popular in all regions of the world, by far the majority of them have happened in the US (Lejon et al., 2009), where dam removal started back in 1931 with removal of dam on the Idaho River (Lejon et al., 2009) and continues to grow still. Doyle et al. (2003) state that by 2003 more than 500 dams have been removed in the United States, while there was no other country that had removed more than nine dams. Lejon et al. (2009) mention, however, that the issues associated with dam removal are the same across the globe.

There are multiple factors, that can induce dam removal. For example, Lejon et al. (2009) indicate that four main reasons for dam removal are safety, law and policy, economy, and ecology; some dams have just lost their presentable look and have been removed as a visual disamenity; Lejon et al. (2009) also add that dam removal can be motivated by climate-related concerns, as it could be a feasible approach to adaptation for escalating climate change (Palmer et al., 2008); Grant and Lewis (2015) find that in the US, in particular, dam removal became a common approach for removing obstruction of fish migration and sediment transport, that restore normal flow and temperature regimes while reconnecting upstream and downstream river flows. To sum it up, we can say that earlier removals were mainly motivated by safety concerns, but during the 1990s environmental motives became more prevalent (Lejon et al., 2009), so that dam removal now has become an increasingly common approach for river restoration in the United States (American Rivers, 2021; Foley et al., 2017; Hart and Poff, 2002; Magilligan et al., 2016; Bednarek, 2001) and has been proven to be an effective approach in that manner (Bednarek, 2001). Increased ecological attention to re-establishing riverine connectivity was one of the main reasons why dam removal became a significant part of the large-scale national-wide restoration process (Magilligan et al., 2016). The age structure of US dams has induced further interest in dam removal (Bellmore et al., 2016; Foley et al., 2017; Doyle et al., 2008; Doyle and Havlick, 2009), as by now over 80% of dams are older than 50 years (USACE, 2018; Doyle et al., 2003).

Evidence from several studies (e.g., Foley et al., 2017; Blachly, 2020; Lewis et al., 2008) allows us to predict that the upward trend in dam removal will continue in the future. Based on the information from the American Rivers' Dam Removal Database[2] (American Rivers, 2020), more than 1600 dams have been removed in the US by February 2021; the majority of them have been

[2] The American Rivers Dam Removal Database is maintained by the non-profit organization American Rivers (http://www.americanrivers.org/) and lists dams that have been removed in the U.S. since 1912 (N = 1668)

removed within the last two decades, while almost 4000 dams were removed globally by 2019 (Ding et al., 2018). Analyzing dam removal trends in the US, Grabowski et al. (2017) estimated that by 2050 between 4 000 and 36 000 dams will be removed. During the past 20 years, dam removal as a concept evolved from a radical idea to a well-established approach for river restoration (Grant and Lewis, 2015). Despite the latter, however, the number of removals remains very modest relative to the number of existing dams. But since the interest in river restoration is only expected to grow in the coming years, it is highly important to understand the trade-offs involved and people's preferences for ecosystem services.

Although the literature on restoration projects and dam removal is quite extensive, very few studies focus on dam removal as a restoration approach, even less consider the socio-economic impacts of dam removal. We contribute to the growing literature that evaluates the benefits of restoration projects and dam removal and add to the scope of research by assessing the economic impacts of dam removal as a river restoration approach. Consideration of socio-economic impacts of restoration projects, that involve dam removal, can complement ecological, hydrological, and geomorphic studies. Dam removal usually entails a large-scale project, that affects the local environment. It is thus reasonable to anticipate that changes caused by dam removal will be reflected in property values.

In this paper we use house sales data for towns in the Penobscot River watershed in Maine, USA (Figure 1) to assess whether the effects of dam removal and river restoration are capitalized in housing prices and in the marginal willingness to pay (MWTP) for river proximity, in particular. We use hedonic property value analysis to provide insights into the value that property owners, as one group of stakeholders, put on the river proximity and improvement of environmental amenities.

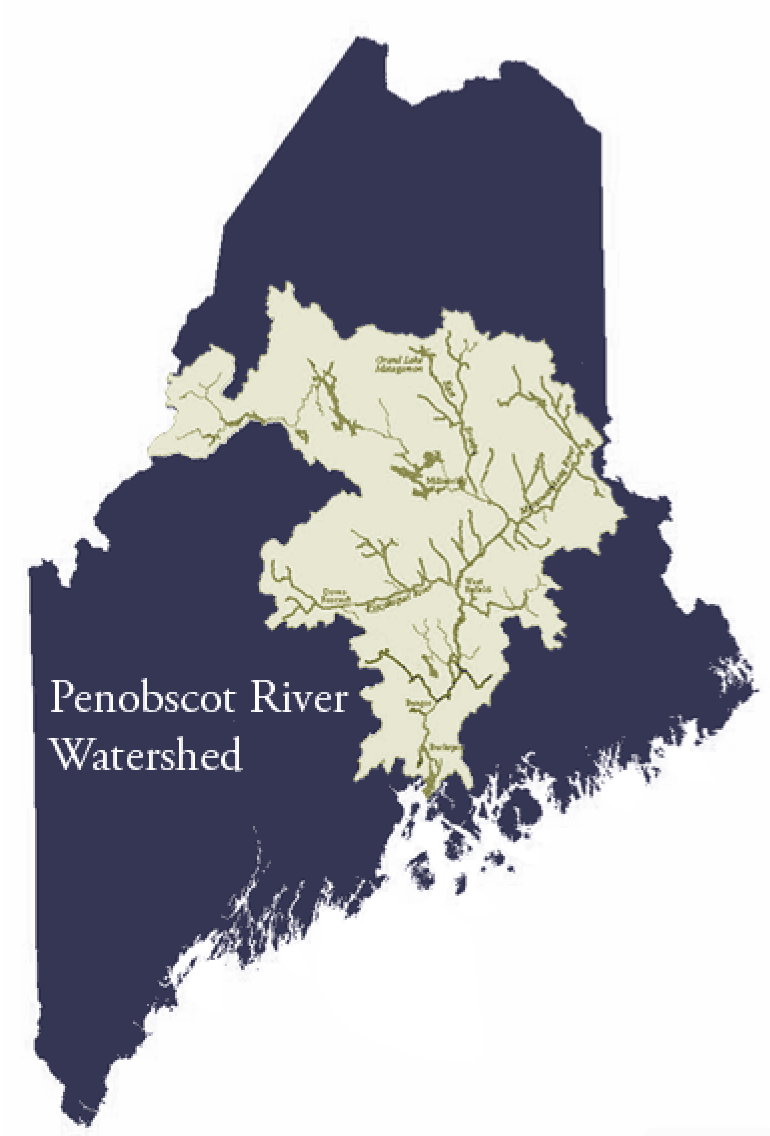

Figure 1. Maine and the Penobscot River Watershed
Source: NRCM, 2018 (https://www.nrcm.org/programs/waters/penobscot-river-restoration-project/)

River proximity was shown to be a disamenity for residential property owners in Maine (Lewis and Landry, 2017; Bohlen and Lewis, 2009), as opposed to one's expectations. After dam removal, however, the disamenity effect of river proximity may decrease or even go away completely, turning proximity into an amenity. The latter may be explained by improved fisheries and water quality, new recreational opportunities, and perhaps the anticipation of more dam removals in the future.

1.2. Dam Removal in Maine and the Penobscot River Restoration Project

Rivers in the eastern US are more dammed than in the rest of the country (Graf, 1999). In the US East, in turn, the New England region[3] has the largest number of dams (Graf, 1993), due to its early European settlements and history of the waterpower-based industry (Magilligan et al., 2016). Located in New England, Maine, where hydropower production accounts for nearly one-third of net electricity (EIA, 2021), was the first state to implement the removal of hydropower dam for the stated purpose of river restoration. In the last 20+ years, Maine has witnessed a number of large-scale dam removal projects, that received significant attention in the literature (Day, 2009; Magilligan et al., 2016; Lewis and Landry, 2017; Lewis et al., 2008; Bohlen and Lewis, 2009; Opperman et al., 2011; Crane, 2009).

Maine rivers have historically hosted paper and clothing mills, log drives, and other production activities. Industries that build up along the rivers contributed to the significant pollution and degradation of Maine rivers (Lewis and Landry, 2017). As a result, opposed to the conventional wisdom that people value houses with close proximity to a water body (see for example Tapsuwan et al., 2012; Landsford and Jones, 1995; Fakhruddin and Espey, 2003; Doss and Taff, 1996; Geoghegan et al., 1997; Mahan et al., 2000; Orford, 2002), Maine houses were historically built facing away from rivers (Lewis and Landry, 2017), and houses closer to rivers were traditionally of a lower value. The latter implies that the conventional environmental amenity – river proximity – is a disamenity for residential property owners along at least some waterways in the state of Maine.

Within the last several decades, intensified concern over sea-run fisheries and a significant decline in activity of paper and textile mills piqued the interest in dam removal in Maine. Besides,

[3] New England is a Northeastern region of the United States of America, that comprises six states: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont

through modern technologies, it is now possible to maintain energy production level despite removal of hydropower dams, by increasing energy generation on other dam sites (which does not block fish passage significantly) and creating innovative constructions, like bypasses. In Maine, it all started with the removal of Edwards dam on Kennebec River in 1999, which launched an immense movement toward small dam removals and river restoration projects across the state (Lewis and Landry, 2017); Crane (2009) indicates that the Edwards dam removal is believed to be the fulcrum in the entire US dam removal movement.

The Penobscot watershed is the second largest river system in New England and the largest in Maine. It boasts a drainage area of over 8.5 thousand square miles, which is almost one-third of the state, and hosts 112 dams, 17 of which are licensed for hydropower generation, producing enough energy to provide electricity to about 155 000 homes with relatively clean energy (Blachly, 2020). The Penobscot River was heavily used for log drives, which together with waste from nearby factories and plants, in addition to general waste from cities and farms, caused tremendous assimilation of waste and water quality degradation (Day, 2009). At the same time, the Penobscot River supports the largest remaining population of wild Atlantic Salmon in the US, which is essential in the prevention of extinction of Atlantic Salmon in Maine (Fay et al., 2006). Dams are barriers that interrupt fish migration and pose a significant threat to the survival of Salmon and other diadromous fishes.

The Penobscot River restoration project (Figure A1) was initiated in 1999 when Pennsylvania Power and Light (PPL) Corporation purchased several dams on the Penobscot River (American Rivers, 2019) and approached the Penobscot Indian Nation with hope of creating a cooperative model for dam relicensing process (The Nature Conservancy, 2021). In 2004, after five years of negotiation, several non-governmental organizations, The Penobscot Tribe, federal and state governments, and hydropower companies formed the Penobscot River Restoration Trust with the intention to find a common solution for a pool of issues, such as hydropower relicensing, fish habitat reconnection, and ecological restoration of the Penobscot River (American Rivers, 2019; NRCM, 2018). Project partners then announced plans for removal of Great Works and Veazie dams (Figures 2 and 3, correspondingly) and increasing electric power generation at other dam sites to maintain hydropower production at the same level (NRCM, 2018; The Nature Conservancy, 2021). It was only in late 2010, however, when the Trust purchased the dams, and the first phase of the project began (NRCM, 2018).

Figure 2. Great Works Dam
Source: NRCM, 2012 (https://www.nrcm.org/programs/waters/penobscot-river-restoration-project/penobscot-river-celebration/)

The Penobscot project is one of the nation's most innovative river restoration projects, as it comprises two dam removals, the construction of the fish bypass, and a few smaller river improvements; it also represents a collaboration of efforts of an unprecedented number of stakeholders. Great Works dam was removed in 2012 and was followed by the removal of the Veazie dam in 2013 and the construction of an innovative river-like fish bypass at Howland dam in 2016. As announced, hydropower generation has been increased at six dam sites in and near the Penobscot watershed, allowing energy generation to remain at the pre-project level despite dam removals (NRCM, 2018).

Figure 3. Veazie Dam
Source: National Geographic (https://blog.nationalgeographic.org/2013/07/22/removal-of-veazie-dam-begins-on-maines-penobscot-river/)

The removed dams blocked fish migration for more than a century, and project partners claim that a number of benefits resulting from the restoration are evident: sea-run fisheries are returning into the newly accessible habitat (Figure A2), nearly 4 000 shad and 1.2 million river herring were found in the new fish lift at the Milford dam in 2017 (with no shad and almost no herring there before the project); sturgeon are also returning to their historic spawning grounds, the Penobscot Nation has hosted several national whitewater canoe races on the newly free-flowing part of the river (NRCM, 2018).

Both Great Works and Veazie dams were relatively small, each 6 meters in height. As with most dams in Maine, these were run-of-the-river and did not create large impoundments, meaning that heavy spring flows were flowing right over the top of dams such that the presence of these dams had minimal impact on flood risk in the region. Thus, flooding issues are not considered a part of the cost of dam removal. While dam removal may seem completely justified in an environmental sense (e.g., from the perspective of fisheries managers), it is usually difficult to account for all social costs and benefits of dams and their removals. Dam removal projects are often controversial, lengthy processes that involve several stakeholders. It is thus highly important to understand the potential benefits and losses of such projects to the fullest. Various values (e.g., recreational, ecosystem, cultural, property) are important for different groups of stakeholders, and residential property owners are just one of them.

In this paper we analyze the removal of Great Works and Veazie dams on the Penobscot River, using 8 years of housing sales data. The hedonic analysis uses observational, non-experimental data, which makes the elicitation of true treatment effect more complicated. Moreover, as houses are neither assigned nor chose to be "treated" (undergo dam removal), it is a researcher's responsibility to determine the boundary between treatment and control group. Lewis et al. (2008), Bohlen and Lewis (2009), and Lewis and Landry (2017) use distance to a river to determine this threshold. We propose to use distance to a dam site to define houses that are affected by dam removal (i.e., houses that are subject to treatment). Additionally, we apply matching methods to compensate for the disadvantages of non-experimental data and obtain a more balanced sample, which should help to reduce bias in the estimated treatment effect of dam removal. While our study only examines the effect of dam removal on property values, with no consideration of other possible benefits and costs associated with the removal, it still carries a capacity to provide helpful information for larger and more integrated analyses and policy decisions.

The remainder of the thesis is organized as follows: Chapter 2 provides a literature review. Chapter 3 describes our data, while Chapter 4 gives a review of our empirical methods. Chapter 5 reports the results for Great Works and Veazie dams. Chapter 6 discusses and concludes.

CHAPTER 2

LITERATURE

A number of dam removals have been examined in the literature, most of them, however, focus on ecological, geomorphic, hydrological, and physical responses of rivers and corresponding ecosystems. Bohlen and Lewis (2009) note that although large dams were studied broadly, smaller dams received very little consideration in the literature. At the same time, a lot of issues associated with dam removals are barely touched or remain unaddressed, and the vast majority of dam removals were neither analyzed nor monitored in any way (Bellmore et al., 2016). According to Bellmore et al. (2016), by the time of their study, only 139 out of 1200 removed dams in the US had any kind of monitoring, and even less received an assessment. Today, the need for post-project monitoring and versatile evaluation, especially socio-economic, is widely recognized (Lewis et al., 2008).

River restoration benefits of dam removal have been discussed in several studies. Magilligan et al. (2016) claim that dam removal leads a river back to a more natural state, and the restoration goal should be self-evident and does not require additional motivation. Lejon et al. (2009) and Wippelhauser et al. (2015) express little doubt that dam removal is an effective approach for fishery restoration and add that it can be a strong incentive for dam removal by itself. A meta-analytic analysis by Foley et al. (2017) synthesizes 207 studies on dam removals in order to assess if it is indeed a helpful approach for river restoration, and how fast river response usually appears. The results show that among the analyzed dam removals, most have been successful and beneficial for ecosystems, while avoided catastrophes. This fact, in turn, indirectly confirms that dam removal will likely remain to be a widely used approach for river restoration in the future. Not everyone agrees, however, that restoration benefits of dam removal are indisputable. Day (2009), for example, puts in doubt the progress of restoring fisheries, and Atlantic Salmon in particular, despite better river conditions at the sites that face dam removal. Magilligan et al. (2016) adds, that in most cases the metric of success remains unclear (e.g., in case of fisheries restoration, is it fish presence, fish abundance, or long-term viability of populations), which is likely caused by the fact that dams are usually removed for a variety of socio-economic reasons without one clearly stated goal.

Discussing 17 dams that were considered for removal in Sweden, Lejon et al. (2009) state that since dam removal initiative may succeed, fail, or result in a compromised outcome, such as a fish bypass, removal projects usually cause controversy. The paper identifies and analyzes three major obstructions to dam removal: funding, cultural and historical values, and uncertainty regarding threatened species, as well as states existing incentives for dam removal, such as safety issues, law and policies, and economic and ecological incentives. Lejon et al. (2009) claim that regardless of the reason for which a dam was initially built and its current usability, at some point of time it became necessary to assess dam's future; in their opinion, if a dam is not in use, there is a good base for its complete removal, at least to avoid potential hazards due to dam failure. A fairly old study by Born et al. (1998) analyses 14 dam removals in Wisconsin, USA, and finds that if a dam needs repair, its estimated cost is on average three times higher than the cost of dam removal.

Brouwer and Sheremet (2017) evaluate advantages and disadvantages of river restoration projects, analyzing forty studies from around the world (Europe, USA, and Australia), that use various revealed and stated preference methods to assess non-market economic values of ecosystem services (including flood, erosion and sediment control, water quality regulation, recreational amenities, landscape aesthetic and biodiversity). The paper comes to the conclusion that, even though the ecological value of ecosystem service is usually obvious, there is often a lack of information regarding wider social value attached to it, which can lead to a lack of support for restoration policy decision making.

Blachly (2020) states that in Maine, in particular, the primary trade-off associated with dam removal is between electric power generation and sea-run fish habitat. Opperman et al. (2015), in turn, analyze the potential for more balanced outcomes of river restoration and hydropower development. They show that even though conservation and hydropower do not always have a common ground, in a lot of cases it is possible to succeed in hydropower development while protecting important ecological values. As they acknowledge that such balanced outcomes may come at additional cost, they state that the latter is usually relatively low, compared to obtained benefits.

Dams block rivers, limiting or even preventing fish movement throughout the system. Limburg and Waldman (2009), and later Blachly (2020) claim that dams are the main reason for the declining population of Atlantic Salmon and its current status as an endangered species. According to Blachly (2020), restoration of endangered Atlantic Salmon is the key benefit from dam removal in the case of Maine and the Penobscot River, specifically. Magilligan et al. (2016) comes to the same conclusion for the whole New England region. While talking about upcoming removals of Great Works and Veazie dams, Day (2009) mentions that scientists consider the Penobscot Project to be the most significant in terms of efforts to restore wild Atlantic Salmon. However, Blachly (2020) itself says that recovery success is not certain. Mills et al. (2013) also says that Atlantic Salmon is a very difficult species to recover, as they suffer from overfishing and climate change, in addition to poor water quality and lost habitat.

Few studies have aimed to analyze the effect of dam removal on residential property values. Lewis et al. (2008) examines consumers' MWTP for being close or distant to a dam site, using hedonic property analysis the paper estimates the effects of the presence and removal of several hydropower dams on the Kennebec River in Maine, USA. The article represents one of the first ex-post analyses of the economic impact of dam removal on property values. They found a penalty for proximity to the dam site. The penalty, however, reduces substantially (from $7.30 to $1.80 per meter) after the removal of Edwards Dam on the Kennebec River in 1999. The paper also examines another real estate market with two functioning dams and finds a significant penalty for dam proximity for each dam site there, which also reduces after the removal of Edwards Dam downstream. Iselin (2008) studies the Androscoggin River in Maine and finds that the negative effect of river proximity on property values disappears after roughly one mile. In the later work, using a hedonic price analysis again, Lewis and Landry (2017) find a positive MWTP for river distance on the Kennebec River before dam removal, that decreases by half after removal (from $3.33 to $1.68 per meter).

Likewise, Bohlen and Lewis (2009) examine whether the closeness of river or hydropower dam affect nearby housing prices, by eliciting MWTP for distance from 2 rivers in Maine, as well as WTP for distance from hydropower dams. While examining the effect of proximity to dams and the Penobscot River on residential property values and comparing results with findings from a similar dataset that contains post dam removal data on properties along the Kennebec River, they found that waterfront homeowners on the Penobscot river and other water bodies pay approximately 16% premium to live on the water. At the same time, landowners pay less to live near the river, than they do to live further away. Looking at the effect of dam proximity on house sales prices, however, they found mixed results.

CHAPTER 3

DATA

For the intended analysis, we utilize single-family home sales data from towns in the Penobscot River watershed in Maine, USA (Figure 4). Our data comes from several sources. Housing transaction data were obtained from Maine Multiple Listing Service (MLS)[4] records of real estate transactions. These data were combined with state of Maine Geographic Information System (GIS) data and data from the U.S. Census (primarily the American Community Survey). Our complete dataset includes information on more than 6 000 residential property sales (N=6089) that occurred during the 8 years period: from 2009 to 2016. The dataset incorporates descriptors of various characteristics of individual houses, geographical location, local economic and landscape conditions, measures of distance to Great Works and Veazie dams and the Penobscot River, as well as demographics. Table 1 provides description of the variables in our dataset. The time frame of the dataset encompasses two dam removals and the construction of the Howland bypass. The latter, however, was constructed in 2016, leaving us with a lack of data for its assessment.

[4] MLS is a private company that maintains a near-complete database of real estate information

Table 1. Variable Descriptions

Variable	Type	Description
price	Continuous	House sales price, adjusted to 2009 US Dollars
baths	Discrete	Bath count
acreage	Continuous	Lot acreage
road frontage	Continuous	Road frontage associated with the property in square feet
rooms	Discrete	Room count
square footage	Continuous	House square footage
waterfront	Binary	=1 if house is a waterfront
house age	Continuous	Age of the house by the time of sale
d_river	Continuous	Distance to the Penobscot River in meters
d_dam	Continuous	Distance to the closest dam in meters
near_gw	Binary	=1 if house is 3000 meters or closer to the Great Works Dam
near_v	Binary	=1 if house is 3000 meters or closer to the Veazie Dam
post_gw	Binary	= 1 if house was sold after Great Works dam removal
post_v	Binary	= 1 if house was sold after Veazie dam removal
developed1500	Continuous	Amount of developed land in the 1500 meters radius from the house
open1500	Continuous	Amount of open space in the 1500 meters radius from the house
income	Discrete	Annual household income (census tract level)
% poverty	Continuous	Percent of people below poverty line in the census tract
d_UofM	Continuous	Distance to the University of Maine in meters
d_Bangor	Continuous	Distance to the Bangor center in meters
old	Binary	=1 if house is 75 years or older

Table 2 provides summary statistics. Sales prices are adjusted to a base value of January 1, 2009, and the average price in the dataset is nearly $158 000. The housing stock in this market is rather old, averaging 56 years, with almost one-third of the houses being older than 75 years. An average house has 6 rooms and 2 bathrooms and totals 1640 square feet with a 1.6-acre lot. The average distance to the Penobscot River is almost 3 kilometers, while the average distance to the nearest dam is slightly more than 9.5 kilometers, and only 6% of houses are waterfront. The average annual household income of homeowners in the dataset is around $52 000, while about 15% of people live below the poverty line. Land use metrics, represented by the amount of developed land and open space within 1 500 meters from each house, are calculated based on Lewis et al. (2008) and Lewis and Landry (2017). The 1 500 meters radius is meant to capture amenities and disamenities that one might face while walking or exercising around a home.

For the proposed analysis, the effects of Great Works dam and Veazie dam removals will be modeled separately. The Great Works dam was removed in June 2012, while the Veazie dam was removed about a year later. Dam removal is a very complicated and lengthy process, so that (1) dam removals in the nearby areas and long negotiation process between stakeholders might cause anticipation effect that can be reflected in house prices even before the removal (Lewis et al., 2008), (2) dam removal benefits do not appear immediately after removal, as river needs time to recover and adjust to new conditions, (3) although most dam removal projects have a specific breach date, a dam is not removed in one day, thus this date is ambiguous. To account for the factors listed above, we drop observations for house sales three months before and three months after each dam removal, as a trade-off between excluding the anticipation and deferred benefits' effects and losing too many observations. Great Works' breach date is June 11th, 2012 (State of Maine Department of Marine Resources, 2012), we thus dropped observations (N=379) from

March-August of that year for Great Works Dam removal analysis. The breach date for the Veazie dam is July 22nd, 2013 (NRCM, 2012), so we drop observations (N=457) from May-October 2013 for the analysis of Veazie removal. This setup leaves us with more than 3 years of pre-removal data and more than 4 years of post-removal data for the Great Works dam. In the case of Veazie dam, we have the opposite: more than 4 years of pre-removal data and more than 3 years of post-removal data.

Table 2. Summary Statistics

Variable	Mean	S.D.	Min	Max
price	157 763.70	76 490.16	21 503.72	442 186.10
baths	1.79	0.70	0.50	6
acreage	1.55	3.85	0.01	47
road frontage	98.52	132.26	0	2 540
rooms	6.25	2.58	0	15
square footage	1 643.03	647.97	300	4 968
waterfront	0.06	0.23	0	1
house age	56.49	42.07	0	242
d_river	2 879.81	3 230.68	1	14 677.91
d_dam	9 605.59	7 026.56	201.35	48 192.08
developed1500	2 167 237	1 840 134	616.22	5 682 656
open1500	3 984 633	1 534 447	104 151.10	6 860 791
income	51 742.14	16 135.60	24 250	82 264
% poverty	15.36	11.63	3.8	47.4
d_UofM	14 850.93	7 724.40	803.46	50 817
d_Bangor	9 212	9 661.10	98.75	63 907.11
old	0.30	0.46	0	1

We realize that not all houses in the dataset might be affected by dam removal and categorize houses in close proximity to one of the dams as treated and those further as controls.

While several previous studies determine the threshold for treatment group based on distance from a river, we propose to utilize distance from a dam site, since a dam is a physical object being removed and is unlikely to remain unnoticed by residential property owners nearby, while it is to be seen if the perception of river proximity for homeowners further from dam site is affected by its removal, even if they are located close to the river.

To obtain some guidance on treatment group selection, we look at the existing literature. Lewis and Landry (2017) use 1100-2500 meters from rivers as a threshold, Provencher et al. (2008) uses only 1/4 of a mile (approximately 402 meters), while Iselin (2008) empirically found that only houses within 1 mile (1 609 meters) from the river are affected by dam removal. Although 500 meters from a dam site (similar to Provencher et al., 2008) seems to be a reasonable distance, at which residents are impacted by nearby dam, we have to rule it out, as we do not have enough transactions for houses that are that close to dam sites in our dataset. We use LOWESS non-parametric smoothing to better understand the relationship between the sales price and distance to our dams, and the point at which they change. Based on the results, 3000 meters from either dam appears to be the most valid distance, at which (1) houses are still within walking distance from the dam, (2) we do have a sufficient number of observations for our analysis, (3) the relationships between the sales price and distance to the dam appears to change for both dam sites in the dataset, (4) mean distance to the Penobscot river for houses in the treatment groups is 480 meters for Great Works dam and 776 meters for Veazie dam, which seem adequate measures for intended analysis. The proposed setup leaves us with 389 observations in the treatment group and 5 321 observations in the control group in the case of Great Works dam, and 238 and 5 394 observations in each group correspondingly in the case of Veazie dam. In this setting, the two specified treatment groups do not intersect with each other (Figure 4), which allows us to conduct separate analyses for each dam removal as intended.

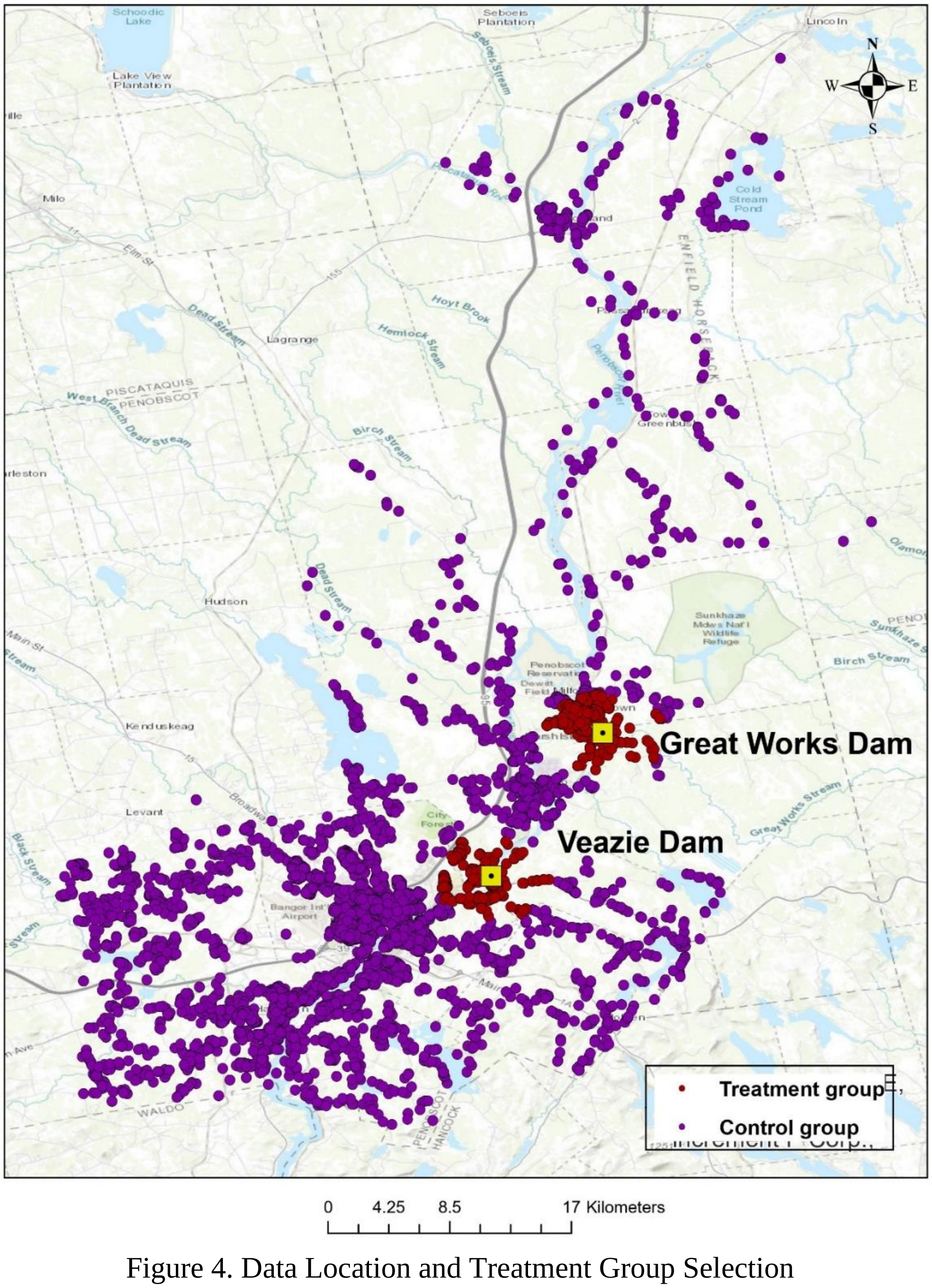

Figure 4. Data Location and Treatment Group Selection

Table A1 provides comparative statistics and t-test comparison of means for treatment and control group for Great Works dam, while Table A2 provides the same for Veazie dam. Houses near Great Works dam are on average much cheaper than houses in the rest of our sample. They have fewer bathrooms and rooms, smaller acreage, square footage, and road frontage, and are on average much older than houses further from Great Works dam. Roughly the same percentage of houses in both groups are waterfront. The amount of developed space is not significantly different for the treatment and control group, while the amount of open space is on average much less for houses near the Great Works dam. Property owners in the treatment group have a significantly lower income and a much higher percentage of people live below the poverty line in the area.

The situation is rather different for Veazie dam. Houses near Veazie dam are on average more expensive and have more rooms and bathrooms. Houses in the treatment group have smaller acreage but larger square footage and are significantly newer. The amount of developed land surrounding houses in the treatment group is significantly smaller, while the amount of open space is significantly larger. Homeowners in the treatment group have a lower income but the percentage of people below poverty line is about the same in both groups.

We can certainly say that not only our treatment groups are different from their corresponding control groups, but that the two treatment groups are significantly different from each other as well. Houses near the Great Works dam seem to differentiate more from the rest of the sample, than houses near the Veazie dam. House sales prices are much lower for houses near Great Works dam, while are much higher for houses near Veazie dam, compared to their control groups. The latter and the other differences can be partially explained by the fact, that the Veazie dam was located between Bangor (the third largest city in Maine) and Orono (home to the

University of Maine). Nonetheless, we can clearly state that in both cases treatment and control groups have different variable distributions.

CHAPTER 4

METHODS

The hedonic price model was first formalized by Griliches (1971) and Rosen (1974) and is now a well-established and widely acknowledged revealed preference non-market valuation technique that utilizes data on real property transactions. The model is mostly used for eliciting values of environmental attributes embedded with residential properties (Evans et al., 2017; Jarrad et al., 2018), such as landscape, noise, air and water quality, etc. Sales price could represent values for a variety of attributes, such as structural characteristics of the property (e.g., number of rooms and bathrooms, lot size), neighborhood characteristics (e.g., local crime rate, proximity to a big city), and local environmental conditions (e.g., water and air quality); hedonic models can help us to determine if a particular environmental good is indeed reflected in the housing market (Lewis et al., 2008). By competing across different house attributes, buyers and sellers generate a sales price for a house, arriving at an equilibrium. The hedonic price function is then used to describe the equilibrium conditions, mapping house attributes in a particular neighborhood and time to its transaction price:

$$P_h = f\left(S_{hj}, N_{hk}, Z_{hm}\right) + e_h \quad (1)$$

where P_h is the sale price of house h; S_{hj} is a j-vector of structural characteristics; N_{hk} is a k-vector of neighborhood characteristics; Z_{hm} is a m-vector of locational and environmental characteristics; and e_h is an independently and identically distributed (i.i.d.) error term.

The hedonic price function (1) thus represents the price of a house as a function of its characteristics. Marginal willingness to pay, which is an implicit price of a particular attribute specified in (1) is represented by a slope of hedonic price function and can be recovered from it, by taking the partial derivative of (1) with respect to the attribute of interest. A positive value of MWTP indicates that homeowners (and sellers) view that attribute as an amenity, while a negative value of MWTP correspondingly indicates that the attribute represents disamenity to property owners. This approach has been widely used to recover MWTP for environmental goods and services in a variety of empirical settings. For example, Evans et al. (2017) use hedonics to recover a value of marine aquaculture, Michael et al. (2000), Huang et al. (2002), and Poor et al. (2007) recover MWTP for water quality, Lewis et al. (2008), Bohlen and Lewis (2009), Lewis and Landry (2017) for proximity to river and dam sites, Gopalakrishnan and Klaiber (2014) and Muehlenbachs et al. (2015) for proximity to hydraulic fracturing well sites.

For our analysis we first need to properly specify a hedonic price function, that will better fit the data and will be able to provide insight on the effect of dam removal on the marginal price of river proximity. There is no theoretical guidance on the functional form of the hedonic regression (Bohlen and Lewis, 2009), however, linear form is ruled out a priori in most cases (Lewis and Landry, 2017). The conventional practice here is to use a semi-logarithmic specification (Lewis et al., 2008; Butsic and Netusil, 2007; Cameron, 2006), that usually provides a good fit, and spatial fixed effects to account for unobserved attributes (Kuminoff et al, 2010). Our main variable of interest is the distance to the Penobscot river, and we expect additional non-linearities in the relationship between the natural log of house sales price and distance to the river. Natural log of distance and inverse distance, both permit diminishing effects, which is expected here, as an equal increase in distance from the river will likely have larger effects for houses located

50 meters away, than for houses located 1 kilometer away from it. Visual analysis of the dataset indicates that the natural log of distance provides for a more suitable model specification, additionally, it offers a simple economic interpretation of the estimates, compared to a more complicated data transformation (e.g., box-cox). Sales prices are normalized to the year 2009 prices, but we also include year fixed effects and season dummies to pick up the remaining time variation, as it is a standard approach to deal with potential time trends and seasonality in prices. Town fixed effects, local economic and demographic characteristics, characteristics of individual houses are added as well to capture spatial variation. To deal with any remaining non-linearities between the natural log of price and independent variables, we fit the natural log of acreage and square footage. Our model thus looks as follows:

$$\ln(P_h) = \beta' x_h + e_h \tag{2}$$

where x_h=[house age, old, rooms, baths, ln(square footage), ln(acreage), waterfront, road frontage, ln(d_river), open1500, developed1500, income, d_Bangor, d_UofM, % poverty, town fixed effects, year fixed effects, season dummies].

To check for causality and obtain the treatment effect of dam removal, however, we need to distinguish the difference in prices for houses that are closer to the dams, as well as pre- and post-removal price differences for them. Difference-in-differences (DnD) model allows us to obtain the latter, while also can help to deal with omitted variable bias, which is also a problem with hedonic models (Jarrad et al., 2018; Ho et al., 2007). We utilize continuous difference-in-differences regression, by adding the following variables to equation (2): post-removal dummy, that will capture raw time effect for all houses in the dataset; interaction of ln(d_river) and treatment group dummy, that is going to represent raw penalty difference between properties in treatment and control group before dam removal; interaction of the latter and post-removal dummy, that under the assumption that the conditional mean of the true error term is zero, provides a true causal effect of dam removal on properties in the treatment group. The complete DnD model for our analysis is specified below:

$$\ln(P_h) = \beta' x_h + post\_dam_h + \ln(d\_river_h) * near\_dam_h + \ln(d\_river_h) * post\_near\_dam_h + e_h \quad (3)$$

where post_dam is either post_gw (=1 if house is sold after Great Works dam removal) or post_v (=1 if house is sold after Veazie dam removal); near_dam is either near_gw (=1 if house is located within 3 000 meters from Great Works dam) or near_v (=1 if house is located within 3 000 meters from Veazie dam); post_near_dam is either post_near_gw (=1 if house is sold after Great Works dam removal and is located within 3 000 meters from it) or post_near_v (=1 if house is sold after Veazie dam removal and is located within 3 000 meters from it).

As our data is observational (non-randomized, non-experimental) and spatially dependent, it is desirable to replicate randomization as closely as possible by obtaining treatment and control groups with similar covariates distributions (Stuart, 2010). We note from Tables A1 and A2, that houses in close proximity to the dams significantly differ from houses further away. The latter means that there is a substantial imbalance on several covariates between treatment and control groups for both dams. To get a better understanding of balance in our data, we calculate standardized mean differences for the covariates of interest (see Table A3 for Great Works dam and Table A4 for Veazie dam), as it is the most common numerical diagnostic (Rosenbaum and Rubin, 1985). The absolute standardized mean difference of more than 0.25 is considered large and needs to be addressed (Rubin, 2001; Stuart, 2010). Based on this threshold, we do not have balance on nine covariates for Great Works dam and only on three covariates for Veazie dam.

Matching procedures aim to balance the covariates' distribution in the treatment and control groups (Stuart, 2010), and reduce bias in treatment effect estimation. Covariate imbalance could also lead to a strong functional form dependence, while matching can reduce the sensitivity in that sense (Blachly, 2020). When dealing with several covariates, as in our case, exact matching does not seem feasible or reasonable. Propensity score, defined as a probability of receiving the treatment given the observed covariates (Rosenbaum and Rubin, 1983), might be a better measure. It summarizes all covariates into a single scalar, which represents the probability of being treated. Various matching methods primarily differ in terms of the number of individuals/units that remain in the pool after matching and the relative weight that each of them receives (Stuart, 2010). One of the most common and easiest methods to implement is nearest neighbor (NN) matching, which allows k:1 matching. NN matching discards control individuals who did not match, and thus estimates only the average effect of treatment on treated (ATT). In our case, this would be the average change in house sales price due to dam removal, which is not of the main interest of our study. By matching procedure, we aim to obtain a more balanced sample, which we are going to use in further analysis to obtain an unbiased estimate of treatment effect in terms of change in the hedonic price of river proximity.

Matching methods have been used in the context of hedonic property value analysis in several studies. For instance, Muehlenbachs et al. (2015) and Delgado et al. (2016) use matching to analyze the effect of natural gas extraction on property values in Pennsylvania. However, these studies utilize matching methods as an alternative to hedonics and only to obtain the treatment effect without further interest in the matched sample. Studies, that use methods other than hedonic analysis, usually also apply matching as an independent or alternative methodology, and not as a supplemental one (see for example Blachly, 2020). We are not aware of existent studies that apply matching as a supplemental method to hedonic analysis and difference-in-differences approach for the purpose of using sample, produced by matching, in further estimations.

We apply a 1:1 nearest neighbor matching with replacement, using a propensity score with a caliper of 0.05 as a distance measure. Although not all covariates in our dataset are imbalanced, it is a common practice to match on all variables, as it helps to reduce the overall bias. While we include all housing and demographic characteristics in the matching procedure, it seems illogical to match on distance variables due to the study design. The small sample sizes of our treatment groups could be a benefit for matching, as we need much more control units than treated to find a better match.

Finally, we run the same DnD regressions only on matched samples and compare results from balanced and unbalanced samples, as well as results from two dam sites.

CHAPTER 5

RESULTS

Before applying any quasi-experimental methods, we estimate a hedonic regression (2) on the whole sample via OLS with heteroskedasticity robust standard errors, to see if the suggested model is reasonable, whether it produces significant results and coefficients' signs consistent with economic theory and our knowledge about the study site. Parameter estimates from this regression are reported in Table 3. All coefficients, except for income are significant at 0.05 level of significance, with the majority of coefficients being significant at alpha of 0.01. The signs of all estimates are consistent with our expectations and economic theory. Older houses on average cost less, and the effect only increases if a house is older than 75 years; room and bath count, as well as square footage and lot acreage increase sale price; homeowners are ready to pay a premium for waterfront homes; road frontage, open and developed space also increase housing price; the further a house is from the Bangor center or the University of Maine, the less its price; higher poverty level implies lower housing prices as well. The coefficient on ln(d_river) is positive, which confirms previous findings, that river proximity is a disamenity at the study site and there is a penalty for living close to the Penobscot River. The log-log functional form with respect to distance to the Penobscot River implies the following form for MWTP for distance from the river:

$$\frac{\partial Price}{\partial d\_river} = \frac{\beta_{\ln(d\_river)}}{d\_river} * Price \tag{4}$$

We evaluate WTP at the mean distance (628.09 meters) and mean price ($145 694.15) across the 2 treatment groups for better comparability of the results and obtain a bootstrapped standard error. The obtained WTP estimate equals $7.42 and is significant at a 99% confidence level. This result implies that on average residential property owners willing to pay $7 420 to be 1 kilometer further away from the river.

Table 3. Hedonic Regression Results

Variable	Coefficient estimate	Robust standard error
house age	-.0034259***[5]	.0002455
old	-.0885778***	.0201765
rooms	.0459581***	.0024757
baths	.1358486***	.0096895
ln(square footage)	.3806554***	.0186232
ln(acreage)	.0392632***	.0063457
waterfront	.2785484***	.0238396
road frontage	.0001233***	.0000341
ln(d_river)	.0319763***	.0063059
open1500	2.15e-08***	4.28e-09
developed1500	2.92e-08***	7.62e-09
income	2.39e-08	1.17e-06
d_Bangor	-6.61e-06**	3.13e-06
d_UofM	-5.94e-06**	2.88e-06
% poverty	-.0026808**	.001099
constant	8.41955***	.1487183
Year fixed effects	YES	
Town fixed effects	YES	
Season fixed effects	YES	
Observations	6089	
R-squared	0.6161	
Dependent variable	ln(price)	

[5] In all tables *, **, *** denote significance at the 10%, 5%, and 1% levels, respectively

5.1. Great Works Dam

Difference-in-differences regression for Great Works dam is estimated via OLS with robust standard errors, clustered at the treatment level, and the results are presented in Table 4, which reports results from both unmatched and matched samples. MWTP values, in turn, can be found in Table 5. In the first (pre-matching) DnD regression, fewer variables are statistically significant (compared to the regression from (2)), even at a 90% confidence level, but all coefficient signs are consistent with those from (2). The coefficient on ln(d_river) is not significant but is practically equal to the estimate from (2). The results indicate that the raw time effect is positive, meaning that house sales prices on average increase post dam removal. The raw effect of being close to the Great Works dam is also positive but neither significant statistically, nor economically, implying that holding everything else constant the penalty for river distance is roughly the same for houses in the treatment and control group. The treatment effect estimate equals -0.0095 and is statistically significant at alpha 0.01. The latter indicates that the proximity penalty slightly reduces for the treatment group after Great Works removal, but the effect is rather small.

Table 4. DnD Regression Results: Great Works Dam

Variable	Coefficient (standard error)	
	Pre- matching	Post- matching
house age	-.0033921** (.0000947)	-.0023919 (.0009375)
old	-.0886923 (.0153232)	-.1687495 (.1000108)
rooms	.0455999** (.0007767)	.0556752* (.0077868)
baths	.1351728** (.0037912)	.1576296 (.0812325)
ln(square footage)	.3806085*** (.001618)	.3542799* (.0310189)
ln(acreage)	.0389581	.0825401

Variable	Coefficient (standard error)	
	Pre- matching	Post- matching
	(.0120343)	(.0906396)
waterfront	.2812746* (.0243456)	.2512888 (.1942197)
road frontage	.0001238* (.0000124)	.000076 (.0001717)
ln(d_river)	.032334 (.0097426)	.0747626 (.0220076)
open1500	2.18e-08 (3.87e-09)	-5.29e-08 (2.18e-08)
developed1500	3.15e-08 (6.07e-09)	-3.58e-08 (3.69e-08)
income	4.07e-07*** (3.94e-09)	-5.64e-06 (3.87e-06)
d_Bangor	-5.59e-06 (7.37e-06)	-.0000344 (.0000303)
d_UofM	-6.36e-06 (1.99e-06)	.0000136 (.0000103)
% poverty	-.0022073** (.0001053)	-.0038007 (.0040461)
ln(d_river)*near_gw	.0002351 (.0135497)	-.0078043* (.0010138)
ln(d_river)*post_near_gw	-.0095152*** (.0001065)	-.0006291 (.0171223)
post_gw	.0465042 (.024104)	.0881181* (.0111462)
constant	8.507092*** (.1500524)	8.974273** (.4393138)
Year fixed effects	YES	YES
Town fixed effects	YES	YES
Season fixed effects	YES	YES
Observations	5710	570
R-squared	0.6158	0.5562
Dependent variable	ln(price)	ln(price)

Willingness to pay estimates (for treatment group before and after treatment, as well as for control group) from the above regression are again evaluated at the mean distance and price across the 2 treatment groups, and bootstrapped standard errors are obtained using 1 000 repetitions. As we can see from Table 5, MWTP for river distance drops by more than $2 (from $7.55 to $5.35) after Great Works removal for houses in the treatment group. The estimated WTP for the control group is nearly the same as for the treatment group before dam removal. All estimates are statistically significant at a 99% confidence level.

Table 5. MWTP for 1 Meter River Distance: Great Works Dam

Treatment group before treatment		Treatment group after treatment		Control group	
Pre- matching	Post- matching	Pre- matching	Post- matching	Pre- matching	Post- matching
7.55*** (1.99)	15.53*** (4.59)	5.35*** (1.92)	15.68*** (4.28)	7.50*** (1.55)	17.34*** (5.28)

Matching produces a more balanced sample and reduces overall bias in the model. Figure A3 shows standardized percent bias across covariates before and after Great Works removal. The covariate imbalance test indicates that mean bias in the sample reduces from 49% to 25%, while median bias reduces from 37% to 24% after matching. A significant difference in standardized means persists for some variables after matching (see also Table A3, last column), however, post-matching results indicate a significant improvement over their pre-matching counterparts.

Our matched sample consists of 570 observations. The results from DnD regression on the matched sample can also be found in Table 4 (last column). Surprisingly, the regression produces even less significant coefficients and a worse fit in terms of R-squared. The coefficient on ln(d_river) is about 2 times larger than ones from the previous models, and the raw time effect is also more substantial. The coefficient on the interaction term between ln(d_river) and near_gw dummy has an alternate sign and is of a much higher magnitude. The treatment effect is now not significant and substantially smaller than the one from the DnD regression before matching. WTP estimates resulting from the regression on the matched sample only (Table 5) are of a significantly higher magnitude; so that, before dam removal MWTP for the treatment group equals $15.53, and it stays roughly the same after Great Works removal. Moreover, the river distance penalty is higher for the control group than those for the treatment group and equals $17.34.

5.2. Veazie Dam

DnD regression results for the Veazie dam are reported in Table 6, where the second column provides estimates from the regression on the unmatched sample. Most coefficient estimates are significant at least at a 90% confidence level, and all signs are consistent with our previous results and economic theory. The coefficient on ln(d_river) is positive, significant at alpha 0.05 and its value is very close to the value from (2) and from DnD regression for the Great Works Dam. As with the Great Works dam, the raw time effect is positive, implying an increase in sales prices following dam removal, but is not significant. The raw proximity effect is also positive and is of a significantly larger magnitude than for the Great Works dam. This estimate is significant at a 90% confidence level and is a signal that the penalty for river proximity is on average higher for homeowners with properties near the Veazie dam. The treatment effect estimate is significant at a 99% confidence level and equals -0.0095, which is roughly the same as for the Great Works dam, indicating that the river proximity penalty for houses near Veazie and Great Works dam reduces evenly after the removal of the nearby dam.

Table 6. DnD Regression Results: Veazie Dam

Variable	Coefficient (standard error)	
	Pre- matching	Post- matching
house age	-.0034664*** (8.16e-06)	-.0034039** (.0001931)
old	-.0921296** (.0062803)	-.1057676** (.0051804)
rooms	.0455955*** (.0006778)	.0268524 (.0047383)
baths	.1367651*** (.001208)	.1603823* (.0147945)
ln(square footage)	.3766366** (.0095886)	.411726* (.0367619)
ln(acreage)	.0406564** (.0017545)	.0541139 (.0150122)
waterfront	.2762678* (.0282261)	.2387338 (.1065643)
road frontage	.0001201** (7.21e-06)	.0002658 (.0002345)
ln(d_river)	.0342833** (.001581)	.041577** (.0022478)
open1500	2.20e-08 (4.69e-09)	-3.57e-08 (3.84e-08)
developed1500	3.07e-08*** (5.66e-11)	1.97e-08 (6.46e-09)
income	-1.59e-07 (7.94e-07)	4.49e-06 (7.15e-06)
d_Bangor	-8.09e-06** (2.00e-07)	-.000029 (.0000241)
d_UofM	-5.47e-06 (9.89e-07)	-6.30e-06 (.0000142)
% poverty	-.0025683 (.0010343)	-.0001899 (.0034197)
ln(d_river)*near_v	.0119324* (.0015427)	.0182535 (.0031172)

Variable	Coefficient (standard error)	
	Pre- matching	Post- matching
ln(d_river)*near_v*post_v	-.0095402*** (.0001307)	-.0125968 (.002781)
post_v	.0395912 (.0108699)	.121821 (.1113155)
constant	8.546215*** (.0078016)	8.549446** (.2647633)
Year fixed effects	YES	YES
Town fixed effects	YES	YES
Season fixed effects	YES	YES
Observations	5632	463
R-squared	0.6105	0.6584
Dependent variable	ln(price)	ln(price)

Table 7 provides WTP estimates from DnD regression for Veazie dam. Estimates from the unmatched dataset show that the penalty for river proximity drops by $2.21 (from $10.72 to $8.51) after Veazie removal for houses in the treatment group. WTP estimate for the control group equals $7.95, which is slightly less than WTP for the treatment group after treatment. All pre-matching estimates are statistically significant at alpha 0.01 and are higher than the estimates for the Great Works dam obtained from the unmatched sample.

Table 7. MWTP for 1 meter river distance: Veazie Dam

Treatment group before treatment		Treatment group after treatment		Control group	
Pre- matching	Post- matching	Pre- matching	Post- matching	Pre- matching	Post- matching
10.72*** (2.20)	13.88*** (5.10)	8.51*** (2.48)	10.96** (5.21)	7.95*** (1.59)	9.64** (4.62)

Matching seems to produce much better results in terms of balancing covariates distribution in the case of Veazie dam , as it reduces mean overall bias in the model from 25.3% to 9.2%, and median bias from 21.5% to 8.8%. We must note, however, that the initial differences in covariate distributions were more substantial for the Great Works dam than for the Veazie dam. Figure A4 shows standardized percent bias across covariates for Veazie dam before and after matching.

We next run the specified DnD regression on the matched sample (N=463), and the corresponding results can be found in the third column of Table 6. The model is a better fit in terms of R-squared, but as with Great Works dam, fewer coefficients are significant post-matching. The coefficient on ln(d_river) is slightly higher than it was before matching, while the time effect has substantially larger magnitude. The penalty for river proximity purely due to closeness to the dam also increases slightly after matching, and so does the treatment effect. The latter though lost its significance as a result of matching.

All post-matching WTP estimates (Table 7, last column) are higher than their pre-matching counterparts and imply a slightly higher penalty reduction: $2.92 compared to $2.21 before matching. Post matching WTP estimate for the control group is also higher than it was before matching and now equals $9.64. In case of Veazie dam WTP estimates resulted from regressions on matched and unmatched samples are consistent with each other and qualitatively similar, so that we observe reduction of WTP for river distance for the treatment group following the Veazie dam removal, and WTP for control group is smaller than both estimates for the treatment group.

CHAPTER 6

CONCLUSIONS

As an increasingly common approach for river restoration, dam removal has the potential for restoring ecosystem functions and recovering fisheries. Along with other trends of our time, dam removal can facilitate water quality improvement, bringing benefits in terms of new recreational end economic opportunities, among others. As the number of dam removal increases and removal as an approach for river restoration becomes more global, it will remain important to study the consequences of dam removal projects for different groups of stakeholders.

Residential property owners are indeed affected by dam removal. Despite some ambiguity in our results, all estimated models show that a penalty for river proximity exists for houses in the Penobscot River watershed and is, perhaps, reflective of the poor environmental quality of Maine rivers due to its past industrial uses. Our results suggest that homeowners willing to pay somewhere from $7.42 to $17.34 for one meter of distance from the river, which implies that they would be willing to pay between an additional $7 420 and $17 340 to be 1 kilometer further away from the river. The latter is consistent with results from previous studies (Lewis et al., 2008; Bohlen and Lewis, 2009; Lewis and Landry, 2017) and our knowledge about the study site. Quantitatively, however, our results are quite noisy. And, although we did not expect that the penalty for river proximity is the same for houses near Veazie and Great Works dam, the results from regressions on matched samples are surprisingly different from those on the unmatched samples in the case of Great Works dam, while appear much more alike and consistent in case of Veazie dam.

Results from DnD regressions for both dams suggest that WTP for river distance reduces after dam removal. The explicit causal interpretation here is that dam removal resulted in improvement of environmental and, perhaps, visual conditions near both dams that have reduced river proximity penalty. It remains unclear, though, why the significance of several coefficients is lost in DnD specifications (especially after matching), while almost all variables were statistically significant at alpha 0.01 in the basic hedonic regression; and whether it means that estimates are not valid. One potential explanation can be increased multicollinearity between variables in the regressions on the matched sample (e.g., average variance inflation factor (VIF) increases from 6.38 to 18.65 after matching in the case of Great Works dam).

The other interpretation of the lost significance after matching are the small sample sizes (570 and 463 for Great Works and Veazie dam correspondingly) resulted from 1:1 NN matching. Matching on a propensity score is a data hungry method, and we suspect that one by one matching is too strict for our data. To check if the insignificance of the coefficient estimates is a result of small pool of matched observations, we also conducted 2:1, 5:1 and 10:1 NN matching for the Great Works dam. Each of the above matching procedures result in larger matched samples and produce qualitatively similar results in terms of DnD regression coefficients and WTP estimates. We need to note, however, that matching with larger number of neighbors, leads to a slight increase in bias, while does not seem to result in a significant increase in efficiency (i.e., the significance/insignificance of coefficients remains the same as with 1:1 matching). We thus can conclude with caution, that the insignificance of coefficient estimates in DnD regressions on the matched samples is unlikely caused by small sizes of the latter.

The insignificance could also result from the fact that we only have one treatment and one control group for each dam site but have to cluster standard errors at the treatment level. Such clustering can be rather conservative and could lead to large standard errors; lower aggregation level of clustering can reduce standard errors but clustering at the treatment level seems the most plausible.

We mentioned that visual analysis of the relationship between distance to the river and house sales price indicates that the log-log model is a better fit than log-reciprocal. A couple of studies, however, used inverse distance specification for a similar analysis, as they found it the most appropriate. Lewis and Landry (2017), for example, use inverse distance specification but note that log-log specification with respect to distance from a river produces similar results. In our case, the inverse distance model produces quite different outcomes, and all WTP estimates resulting from it are not statistically significant. It remains ambiguous then, if our results are not robust to the model specification or if our dataset is fairly different from that of previous studies, and the inverse distance model just does not fit the data.

Looking at the results from previous studies on dam removal impacts on property values in Maine (Lewis et al., 2008; Bohlen and Lewis, 2009; Lewis and Landry, 2017) it seems that estimates from DnD regressions on the unmatched samples are the most reliable, as the magnitude of coefficients is consistent with that from existing literature. Matching produced a more balanced sample and qualitatively consistent results in terms of WTP estimates in case of Veazie dam. For Great Works dam, however, matching did not result in satisfactory bias reduction and produced quite ambiguous results, both qualitatively and quantitatively.

Another interesting fact is that, while treatment and control groups are much similar for Veazie dam, and the geographical location of houses in the treatment group suggests that dam presence or absence might not be as important for property owners (due to other locational attributes that could compensate disamenity effects caused by the dam), river proximity penalty is higher for property owners near Veazie dam compared to Great Works, while penalty reduction following dam removal is roughly the same for both dam sites.

While we should interpret our quantitative results with caution, the obtained qualitative results are fairly robust. The main cause of ambiguity in the quantitative results is the lack of strict boundaries for treatment and control groups. Treatment group definition determines not only the pool of houses that assumed to be affected by dam removal, but also mean distance and price values at which WTP estimates are evaluated. We attempted to test three definitions of treatment group, other than our main specification for the Great Works dam: 5 000 and 1 500 meters from the Great Works dam and 500 meters from the Penobscot River (excluding houses near the Veazie dam). There is not enough data, however, to estimate a significant effect if we only consider houses within 1 500 meters from Great Works Dam subjects to treatment. WTP estimates from DnD regressing obtained using the other two treatment groups are reported in Table A5. The results indicate that penalty reduction after dam removal remains in place no matter how we determine the treatment group (within reasonable limits), but WTP values are highly dependent on the ambiguous treatment group selection. Given the latter, we might suspect that the estimates from the existent literature (e.g., Lewis and Landry, 2017) are ambiguous as well, as they are also based on the treatment group definition made by the researchers.

Though our study has a few limitations that can be addressed in future research, it does provide important clues for the question asked. Our results confirm, that as for other rivers in Maine, there is a penalty for river proximity for houses located near the Penobscot River. Dam removal reduces that penalty, making houses near the river more attractive for property owners. It is obvious that the penalty and the effects of dam removal depend on multiple factors and are not the same for any two sites. Combining our results with previous findings on Maine dam removal, we can once again affirm that dam removal as a restoration approach has a positive effect on house sales prices. Although in the time frame of our study the river proximity penalty did not go away completely, more long-term multidisciplinary studies are needed in order to understand if and when it can disappear, turning the river proximity into an amenity. As more time passes after dam removal, a study can be conducted again using a different or extended sample size, to observe how the disamenity effect evolve over time. Larger sample size can also provide enough data for a more narrow treatment group definition (e.g., 1 000 meters or 500 meters from a dam site). Supplementary methods, such as surveys or interviews with homeowners can be applied as well to elicit people's perceptions of river proximity and consequences of dam removal.

REFERENCES

American Rivers. (2020). *American rivers dam removal database*. https://doi.org/10.6084/m9.figshare.5234068 (accessed: 02.23.2021)

American Rivers. (2019). *Penobscot River Dams.* https://www.americanrivers.org/penobscot-river-dams/ (accessed: 06.23.2021)

American Rivers. (2021). *Restoring damaged rivers*. https://www.americanrivers.org/threats-solutions/restoring-damaged-rivers/ (accessed: 02.03.2010)

Auerbach, D. A., Deisenroth, D. B., McShane, R. R., McCluney, K. E., and Poff, N. L. (2014). Beyond the concrete: Accounting for ecosystem services from free-flowing rivers. *Ecosystem Services*, *10*, 1–5. https://doi.org/https://doi.org/10.1016/j.ecoser.2014.07.005

Bednarek, A. T. (2001). Undamming rivers: A review of the ecological impacts of dam removal. *Environmental Management*, *27*, 803–814. https://doi.org/10.1007/s002670010189

Bellmore, R. J., Duda, J. J., Craig, L. S., Greene, S. L., Torgersen, C. E., Collins, M. J., & Vittum, K. (2016). Status and trends of dam removal research in the United States. *WIREsWater*, *4*(2), e1164. https://doi.org/https://doi.org/10.1002/wat2.1164

Blachly, B. (2020). *Essays on economics of ecosystem services from damremoval to improve decision making* (Open Access Dissertations). University of Rhode Island. https://digitalcommons.uri.edu/oa_diss/1191

Bohlen, C., and Lewis, L. Y. (2009). Examining the economic impacts of hydropower dams on property values using GIS. *Journal of Environmental Management*, *90*, S258–S269. https://doi.org/https://doi.org/10.1016/j.jenvman.2008.07.026

Born, S. M., Genskow, K. D., Filbert, T. L., Hernandez-Mora, N., Keefer, M. L., and White, K. A. (1998). Socioeconomic and institutional dimensions of dam removals: The Wisconsin experience. *Environ Manage*, *22*, 359–370. https://doi.org/10.1007/s002679900111

Brouwer, R., and Sheremet, O. (2017). The economic value of river restoration. *Water Resources and Economics*, *17*. https://doi.org/10.1016/j.wre.2017.02.005

Butsic, V., and Netusil, N. R. (2007). Valuing water rights in Douglas county, Oregon, using the hedonic price method. *JAWRA Journal of the American Water Resources Association*, *43*(3), 622–629. https://doi.org/https://doi.org/10.1111/j.1752-1688.2007.00049.x

Cameron, T. A. (2006). Directional heterogeneity in distance profiles in hedonic property value models. *Journal of Environmental Economics and Management*, *51*(1), 26–45. https://ideas.repec.org/a/eee/jeeman/v51y2006i1p26-45.html

Crane, J. (2009). ‘‘Setting the river free”: The removal of the edwards dam and the restoration of the kennebec river. *Water History*, *1*, 131–148. https://doi.org/10.1007/s12685-009-0007-2

Day, L. (2009). Restoring native fisheries to maine’s largest watershed: The Penobscot River restoration project. *Journal of Contemporary Water Research Education*, *134*, 29–33. https://doi.org/10.1111/j.1936-704X.2006.mp134001006.x

Delgado, M. S., Guilfoos, T., and Boslett, A. (2016). The cost of unconventional gas extraction: A hedonic analysis. *Resource and Energy Economics*, *46*, 1-22. doi:https://doi.org/10.1016/j.reseneeco.2016.07.001

Ding, L., Liqiang, C., Ding, C., and Tao, J. (2018). Global trends in dam removal and related research: A systematic review based on associated datasets and bibliometric analysis. *Chinese Geographical Science*. https://doi.org/10.1007/s11769-018-1009-8

Doss, C., and Taff, S. (1996). The influence of wetland type and wetland proximity on residential property values. *Journal of Agricultural and Resource Economics*, *21*(1), 30992. https://EconPapers.repec.org/RePEc:ags:jlaare:30992

Doyle, M., Stanley, E., Havlick, D., Kaiser, M., Steinbach, G., Graf, W., Galloway, G., and Riggsbee, A. (2008). Aging infrastructure and ecosystem restoration. *Science*, *319*, 286–287. https://doi.org/10.1126/science.1149852

Doyle, M.W., and Havlick, D. G. (2009). Infrastructure and the environment. *Annual Review of Environment and Resources*, *34*(1), 349–373. https://doi.org/10.1146/annurev.environ.022108.180216

Doyle, M.W., Stanley, E. H., and Harbor, J. M. (2003). Channel adjustments following two dam removals in Wisconsin. *Water Resources Research*, *39*(1). https://doi.org/https://doi.org/10.1029/2002WR001714

Evans, K. S., Chen, X., and Robichaud, C. A. (2017). A hedonic analysis of the impact of marine aquaculture on coastal housing prices in Maine. *Agricultural and Resource Economics Review*, *46*(2), 242–267. https://doi.org/10.1017/age.2017.19

Fakhruddin, F., and Espey, M. (2003). *Living on the edge: Residential property values in the urban/rural fringe?* (2003 Annual meeting, July 27-30, Montreal, Canada No. 22072). American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association). https://doi.org/10.22004/ag.econ.22072

Fay, C., Bartron, M., Craig, S. D., Hecht, A., Pruden, J., Saunders, R., Sheehan, T. F., Trial, J. G., and McCollough, M. (2006). Status review for anadromous Atlantic salmon (salmo salar) in the united states. https://repository.library.noaa.gov/view/noaa/4550

Foley, M. M., Bellmore, J. R., O’Connor, J. E., Duda, J. J., East, A. E., Grant, G. E., Anderson, C.W., Bountry, J. A., Collins, M. J., Connolly, P. J., Craig, L. S., Evans, J. E., Greene, S. L.,Magilligan, F. J.,Magirl, C. S.,Major, J. J., Pess, G. R., Randle, T. J., Shafroth, P. B., ... Wilcox,

A. C. (2017). Dam removal: Listening in. *Water Resources Research*, *53*(7), 5229–5246. https://doi.org/https://doi.org/10.1002/2017WR020457

Geoghegan, J.,Wainger, L. A., and Bockstael, N. E. (1997). Spatial landscape indices in a hedonic framework: An ecological economics analysis using GIS. *Ecological Economics*, *23*(3), 251–264. https://EconPapers.repec.org/RePEc:eee:ecolec:v:23:y:1997:i:3:p:251-264

Gopalakrishnan, S., and Klaiber, H. A. (2014). Is the shale energyboom a bust for nearby residents? Evidence from housing values in Pennsylvania. *American Journal of Agricultural Economics*, *96*(1), 43–66. https://doi.org/https://doi.org/10.1093/ajae/aat065

Grabowski, Z., Denton, A., Rozance, M., Matsler, M., and Kidd, S. (2017). Removing dams, constructing science: Coproduction of undammed riverscapes by politics, finance, environment, society and technology. *Water Alternatives*, *10*, 769–795.

Graf, W. L. (1993). *Landscapes, commodities and ecosystems: The relationship between policy and science for american rivers*. National Academies Press.

Graf, W. L. (1999). Dam nation: A geographic census of american dams and their large-scale hydrologic impacts. *Water Resources Research*, *35*(4), 1305–1311. https://doi.org/https://doi.org/10.1029/1999WR900016

Grant, G., and Lewis, S. (2015). Engineering geology for society and territory - volume 3. https://doi.org/10.1007/978-3-319-09054-2_7

Griliches, Z. (1961). The price statistics of the federal government. NBER. http://www.nber.org/chapters/c6492

Hart, D. D., and Poff, N. L. (2002). A special section on dam removal and river restoration. *BioScience*, *52*(8), 653–655. https://doi.org/10.1641/0006-3568(2002)052[0653:ASSODR]2.0.CO;2

Ho, D., Imai, K., King, G., and Stuart, E. (2007). Matching as Nonparametric Preprocessing for Reducing Model Dependence in Parametric Causal Inference. Political Analysis, 15, 199–236.

Huang, J.-C., Boyle, K. J., Halstead, J. M., and Gibbs, J. P. (2002). An hedonic analysis of the effects of lake water clarity on New Hampshire lakefront properties. *Agricultural and Resource Economics Review*, (1203-2016-94978), 8. https://doi.org/10.22004/ag.econ.31475

Iselin, J. (2008). *A river ran through it: Implicit prices in the Lewiston-Auburn housing market.* (Undergraduate thesis). Bates College. Lewiston, ME.

Jansson, R., Nilsson, C., Dynesius, M., and Elisabet, A. (2000). Effects of river regulation on river-margin vegetation: A comparison of eight boreal rivers. *Ecological Applications*, *10*, 203–224. https://doi.org/10.2307/2640996

Jarrad, M., Netusil, N., Moeltner, K., Morzillo, A., and Yeakley, A. (2018). Urban stream restoration projects: Do project phase, distance, and type affect nearby property sale prices? *Land Economics*, *94*, 368–385. https://doi.org/10.3368/le.94.3.368

Kingsford, R. (2000). Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology*, *25*, 109–127. https://doi.org/10.1046/j.1442-9993.2000.01036.x

Kuminoff, N. V., Parmeter, C. F., and Pope, J. C. (2010). Which hedonic models can we trust to recover the marginal willingness to pay for environmental amenities? *Journal of Environmental Economics and Management*, *60*(3), 145-160. https://doi.org/10.1016/j.jeem.2010.06.001

Landsford, N., and Jones, L. (1995). Recreational and aesthetic value of water using hedonic price analysis. *Journal of Agricultural and Resource Economics*, *20*(2), 341–355. http://www.jstor.org/stable/40987743

Lejon, A. G. C., Malm Renöfält, B., and Nilsson, C. (2009). Conflicts associated with dam removal in Sweden. *Ecology and Society*, *14*(2). http://www.jstor.org/stable/26268322

Lewis, L. Y., Bohlen, C., and Wilson, S. (2008). Dams, dam removal, and river restoration: A hedonic property value analysis. *Contemporary Economic Policy*, *26*(2), 175–186. https://doi.org/https://doi.org/10.1111/j.1465-7287.2008.00100.x

Lewis, L. Y., and Landry, C. E. (2017). River restoration and hedonic property value analyses: Guidance for effective benefit transfer [Economics of River Restoration]. *Water Resources and Economics*, *17*, 20–31. https://doi.org/https://doi.org/10.1016/j.wre.2017.02.001

Limburg, K. E., and Waldman, J. R. (2009). Dramatic declines in north Atlantic diadromous fishes. *Bio-Science*, *59*(11), 955–965. https://doi.org/10.1525/bio.2009.59.11.7

Magilligan, F., Graber, B., Nislow, K., Chipman, J., Sneddon, C., and Fox, C. (2016). River restoration by dam removal: Enhancing connectivity at watershed scales. *Elementa: Science of the Anthropocene*, *4*, 000108. https://doi.org/10.12952/journal.elementa.000108

Mahan, B. L., Polasky, S., and Adams, R. M. (2000). Valuing urban wetlands: A property price approach. *Land Economics*, *76*(1), 100–113. https://doi.org/10.2307/3147260

Michael, H. J., Boyle, K. J., and Bouchard, R. (2000). Does the measurement of environmental quality affect implicit prices estimated from hedonic models? *Land Economics*, *76*(2), 283–298. https://ideas.repec.org/a/uwp/landec/v76y2000i2p283-298.html

Mills, K. E., Pershing, A. J., Sheehan,T. F., and Mountain, D. (2013). Climate and ecosystem linkages explain widespread declines in north american Atlantic salmon populations. *Global Change Biology*, *19*(10), 3046–3061. https://doi.org/https://doi.org/10.1111/gcb.12298

Muehlenbachs, L., Spiller, E., and Timmins, C. (2015). The housing market impacts of shale gas development. *The American Economic Review*, *105*(12), 3633–3659. http://www.jstor.org/stable/43821388

Nilsson, C., Reidy, C. A., Dynesius, M., and Revenga, C. (2005). Fragmentation and flow regulation of the world's large river systems. *Science*, *308*(5720), 405–408. https://doi.org/10.1126/science.1107887

Natural Resources Council of Maine (NRCM). (2012). *Veazie dam removal on the Penobscot River*. https://www.nrcm.org/programs/waters/penobscot-river-restoration-project/veazie-dam/ (accessed: 05.09.2021)

Natural Resources Council of Maine (NRCM). (2018). *Penobscot river restoration project*. https://www.nrcm.org/programs/waters/penobscotriver-restoration-project/ (accessed: 12.13.2020)

Opperman, J., Royte, J., Banks, J., Day, L. R., and Apse, C. (2011). The Penobscot River, Maine, USA: A basin-scale approach to balancing power generation and ecosystem restoration. *Ecology and Society*, *16*.

Opperman, J., Grill, G., Hartmann, J., Angarita, H., Bara, P., Delgado, J., Harrison, D., Higgins, J., Martin, E., Newsock, A., Petry, P., Roth, B., Sotomayor, L., Torres, J., and Vázquez, D. (2015). *The power of rivers: Finding balance between energy and conservation in hydropower development* (tech. rep.). The Nature Conservancy. https://doi.org/10.13140/RG.2.1.5054.5765

Orford, S. (2002). Valuing locational externalities: A GIS and multilevel modelling approach. *Environment and Planning B: Planning and Design*, *29*, 105–127. https://doi.org/10.1068/b2780

Palmer, M. A., Reidy Liermann, C. A., Nilsson, C., Flörke, M., Alcamo, J., Lake, P. S., and Bond, N. (2008). Climate change and the world's river basins: Anticipating management options. *Frontiers in Ecology and the Environment*, *6*(2), 81–89. https://doi.org/https://doi.org/10.1890/060148

Poor, P. J., Pessagno, K. L., and Paul, R.W. (2007). Exploring the hedonic value of ambient water quality: A local watershed-based study. *Ecological Economics*, *60*(4), 797–806. https://EconPapers.repec.org/RePEc:eee:ecolec:v:60:y:2007:i:4:p:797-806

Provencher, B., Sarakinos, H., and Meyer, T. (2008). Does small dam removal affect local property values? An empirical analysis. *Contemporary Economic Policy*, *26*(2), 187–197. https://doi.org/https://doi.org/10.1111/j.1465-7287.2008.00107.x

Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of Political Economy*, *82*(1), 34–55. http://www.jstor.org/stable/1830899

Rosenbaum, P. R., and Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, *70*(1), 41–55. https://doi.org/10.1093/biomet/70.1.41

Rosenbaum, P. R., and Rubin, D. B. (1985). Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *The American Statistician*, *39*(1), 33–38. http://www.jstor.org/stable/2683903

Rubin, D. B. (2001). Using propensity scores to help design observational studies: Application to the tobacco litigation. *Health Services and Outcomes Research Methodology*, *2*, 169–188.

Shuman, J. R. (1995). Environmental considerations for assessing dam removal alternatives for river restoration. *Regulated Rivers: Research & Management*, *11*(3-4), 249–261. https://doi.org/https://doi.org/10.1002/rrr.3450110302

State of Maine Department of Marine Resources. (2012). *Penobscot River restoration project - Great Works dam removal*. https://www.maine.gov/dmr/science-research/searun/programs/greatworksdam.html (accessed: 05.09.2021)

Stuart, E. A. (2010). Matching methods for causal inference: A review and a look forward. *Statistical science: a review journal of the Institute of Mathematical Statistics*, *25*, 1–21. https://doi.org/10.1214/09-STS313

Syvitski, J. P. M., Vörösmarty, C. J., Kettner, A. J., and Green, P. (2005). Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science*, *308*(5720), 376–380. https://doi.org/10.1126/science.1109454

Tapsuwan, S., MacDonald, D. H., King, D., and Poudyal, N. (2012). A combined site proximity and recreation index approach to value natural amenities: An example from a natural resource management region of murray-darling basin. *Journal of Environmental Management*, *94*(1), 69–77. https://doi.org/https://doi.org/10.1016/j.jenvman.2011.07.003

The Nature Conservancy. (2021). *Restoring The Penobscot River*. https://www.nature.org/en-us/about-us/where-we-work/united-states/maine/stories-in-maine/restoring-the-penobscot-river/ (accessed: 06.23.2021)

United States Army Corps of Engineers (USACE). (2018). *National inventory of dams*. https://nid.sec.usace.army.mil (accessed: 12.11.2020)

U.S. Energy Information Administration (EIA). (2021). *Maine - state energy profile overview*. https://www.eia.gov/state/?sid=ME (accessed: 05.05.2021)

Vermaat, J., Wagtendonk, A., Brouwer, R., Sheremet, O., Ansink, E., Brockhoff, T., Plug, M., Hellsten, S., Aroviita, J., Tylec, L., Giełczewski, M., Okruszko, T., Kohut, L., Brabec, K., Haverkamp, J., Poppe, M., Böck, K., Coerssen, M., Segersten, J., and Hering, D. (2016). Assessing the societal benefits of river restoration using the ecosystem services approach. *Hydrobiologia*, *769*. https://doi.org/10.1007/s10750-015-2482-z

Wang, Z.-Y., Lee, J. H., and Melching, C. S. (2014). *River dynamics and integrated river management*. Springer Berlin Heidelberg. https://books.google.com/books?id=pgacBAAAQBAJ

Ward, J. V., and Stanford, J. A. (1995). Ecological connectivity in alluvial river ecosystems and its disruptionby flow regulation. *Regulated Rivers: Research & Management*, *11*(1), 105–119. https://doi.org/https://doi.org/10.1002/rrr.3450110109

Whitelaw, E., and Macmullan, E. (2002). A framework for estimating the costs and benefits of dam removal: Sound cost–benefit analyses of removing dams account for subsidies and externalities, for both the short and long run, and place the estimated costs and benefits in the appropriate economic context. *BioScience*, *52*(8), 724–730. https://doi.org/10.1641/0006-3568(2002)052[0724:AFFETC]2.0.CO;2

Wippelhauser, G., Zydlewski, G., Kieffer, M., Sulikowski, J., & Kinnison, M. (2015). Shortnose sturgeon in the gulf of Maine: Use of spawning habitat in the Kennebec system and response to dam removal. *Transactions of the American Fisheries Society*, *144*, 742–752. https://doi.org/10.1080/00028487.2015.1037931

World Commission on Dams. (2000). *Dams and development: A new framework for decision-making: The report of the world commission on dams*. Earthscan.

APPENDIX

Table A1. T-test Comparison of Means: Great Works Dam

Variable	Mean		Comparison	
	ngw=1	ngw=0	t-stat	p-value
price	103112.60	161276.20	-14.76	0.000
baths	1.53	1.81	-7.78	0.000
acreage	0.61	1.62	-5.03	0.000
road frontage	61.81	100.92	-5.67	0.000
rooms	5.66	6.28	-4.55	0.000
square footage	1473.55	1657.47	-5.40	0.000
waterfront	0.06	0.06	0.23	0.817
house age	76.41	55.33	9.62	0.000
developed1500	2208557	2167832	0.42	0.674
open1500	3566989	4010815	-5.52	0.000
income	32723.30	53138.60	-25.36	0.000
% poverty	26.60	14.56	20.39	0.000
old	0.54	0.29	10.61	0.000

Table A2. T-test Comparison of Means: Veazie Dam

Variable	Mean		Comparison	
	ngw=1	ngw=0	t-stat	p-value
price	188275.70	155507.80	6.51	0.000
baths	1.96	1.78	3.88	0.000
acreage	0.98	1.57	-2.30	0.021
road frontage	91.41	98.78	-0.83	0.404
rooms	6.76	6.21	3.20	0.001
square footage	1768.93	1631.47	3.22	0.001
waterfront	0.08	0.06	1.78	0.075
house age	49.68	56.87	-2.59	0.010
developed1500	1352981	2207843	-7.04	0.000
open1500	4828069	3946108	8.75	0.000
income	49086.97	51783.51	-2.52	0.012
% poverty	15.68	15.39	0.37	0.714
old	0.21	0.31	-3.27	0.001

Table A3. Standardized Mean Differences: Great Works Dam

Variable	Standardized mean difference (near_gw=0 vs near_gw=1)	
	Before matching	After matching
house age	**-0.54120**	**-0.37798**
old	**-0.53446**	**-0.50205**
rooms	0.23316	-0.02809
baths	**0.45054**	0.02935
square footage	**0.31451**	-0.03664
acreage	**0.29961**	0.23118
waterfront	0.01207	0.13903
road frontage	**0.36506**	0.12140
open1500	**0.36922**	**0.37316**
developed1500	-0.02867	**-0.27248**
income	**1.50133**	**0.74367**
% poverty	**-1.16610**	**-0.65218**

Table A4. Standardized Mean Differences: Veazie Dam

Variable	Standardized mean difference (near_v=0 vs near_v=1)	
	Before matching	After matching
house age	0.16353	-0.09184
old	0.22859	-0.07006
rooms	-0.21927	-0.10741
baths	**-0.25964**	-0.12139
square footage	-0.21128	-0.19618
acreage	0.17205	0.12381
waterfront	0.10769	0.06262
road frontage	0.06262	-0.05771
open1500	**-0.73932**	-0.10380
developed1500	**0.61697**	-0.09059
income	0.22556	-0.13209
% poverty	-0.02939	0.06787

Table A5. MWTP for 1 Meter River Distance: Great Works Dam (Additional Estimations)

Treatment group before treatment		Treatment group after treatment		Control group	
Pre- matching	Post- matching	Pre- matching	Post- matching	Pre- matching	Post- matching
Treatment group = houses within 5 000 meters from the dam					
9.44*** (1.84)	13.04*** (3.23)	7.91*** (1.68)	12.63*** (3.11)	6.09*** (1.39)	8.50** (3.88)
Treatment group = houses within 500 meters from the river					
19.30*** (5.56)	22.91*** (7.32)	13.27** (5.38)	16.20** (7.64)	15.81*** (4.37)	18.18*** (5.73)

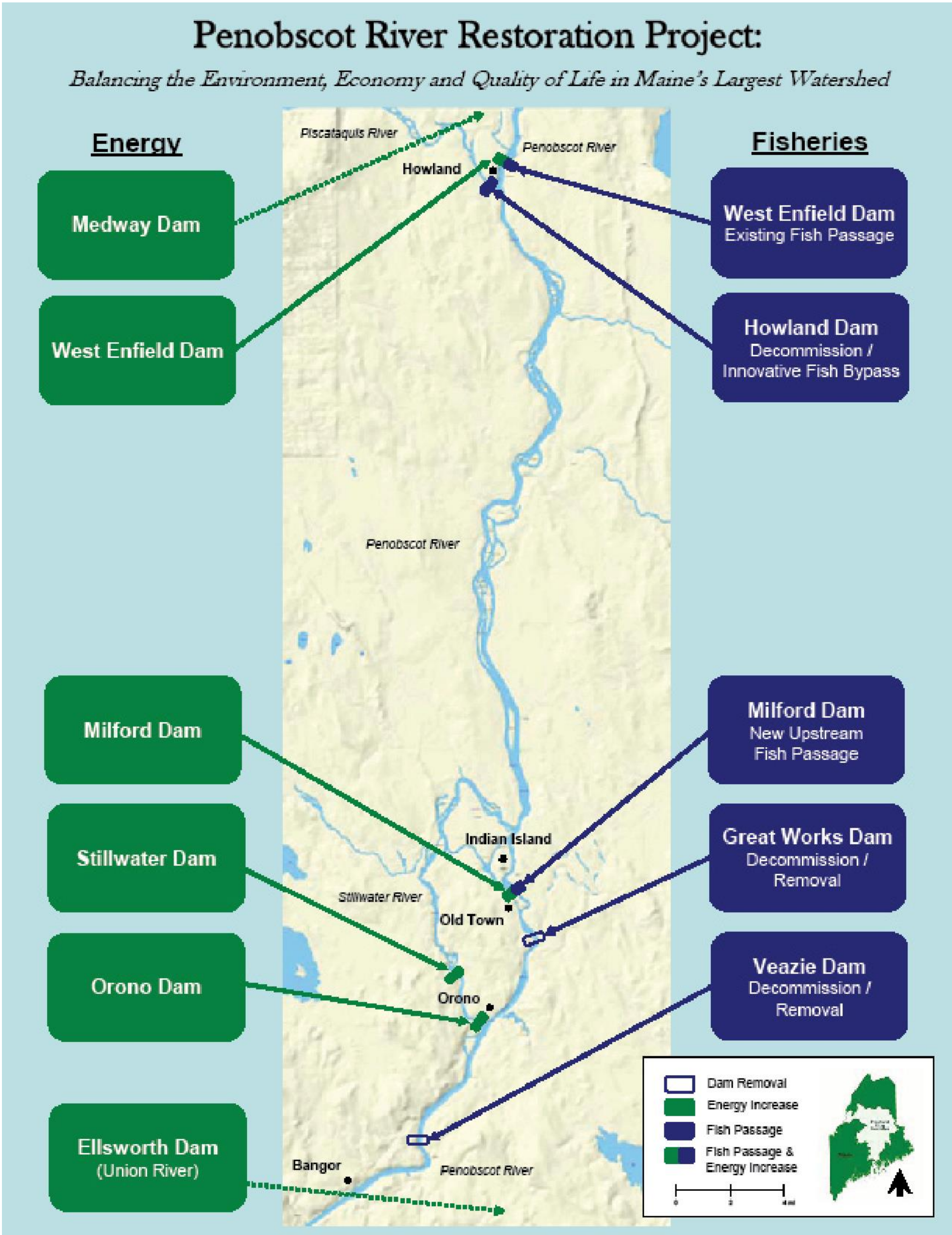

Figure A1. Penobscot River Restoration Project Map
Source: NRCM, 2018 (https://www.nrcm.org/wp-content/uploads/2018/11/Penobscotprojectmap.pdf)

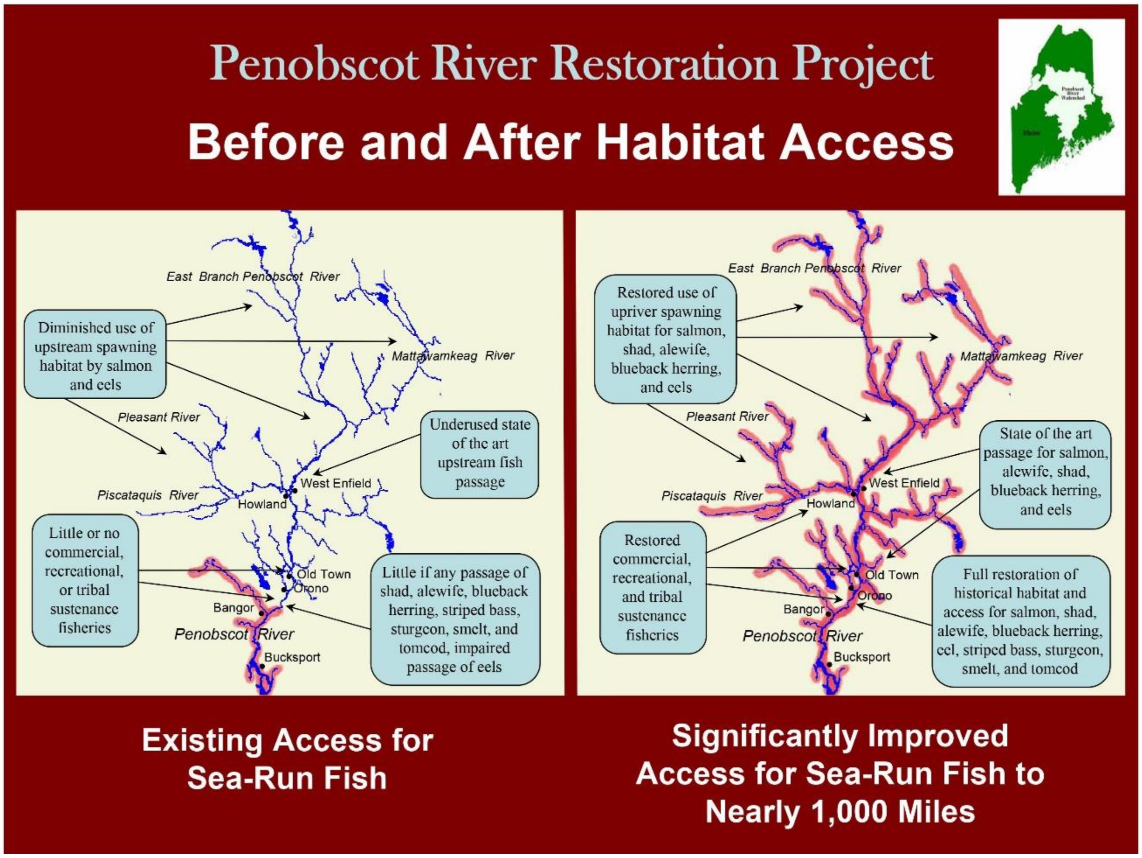

Figure A2. Habitat Access Before and After Penobscot River Restoration Project
Source: NRCM, 2018 (https://www.nrcm.org/wp-content/uploads/2018/11/HabitatAccessbeforeandafterPRRP.pdf)

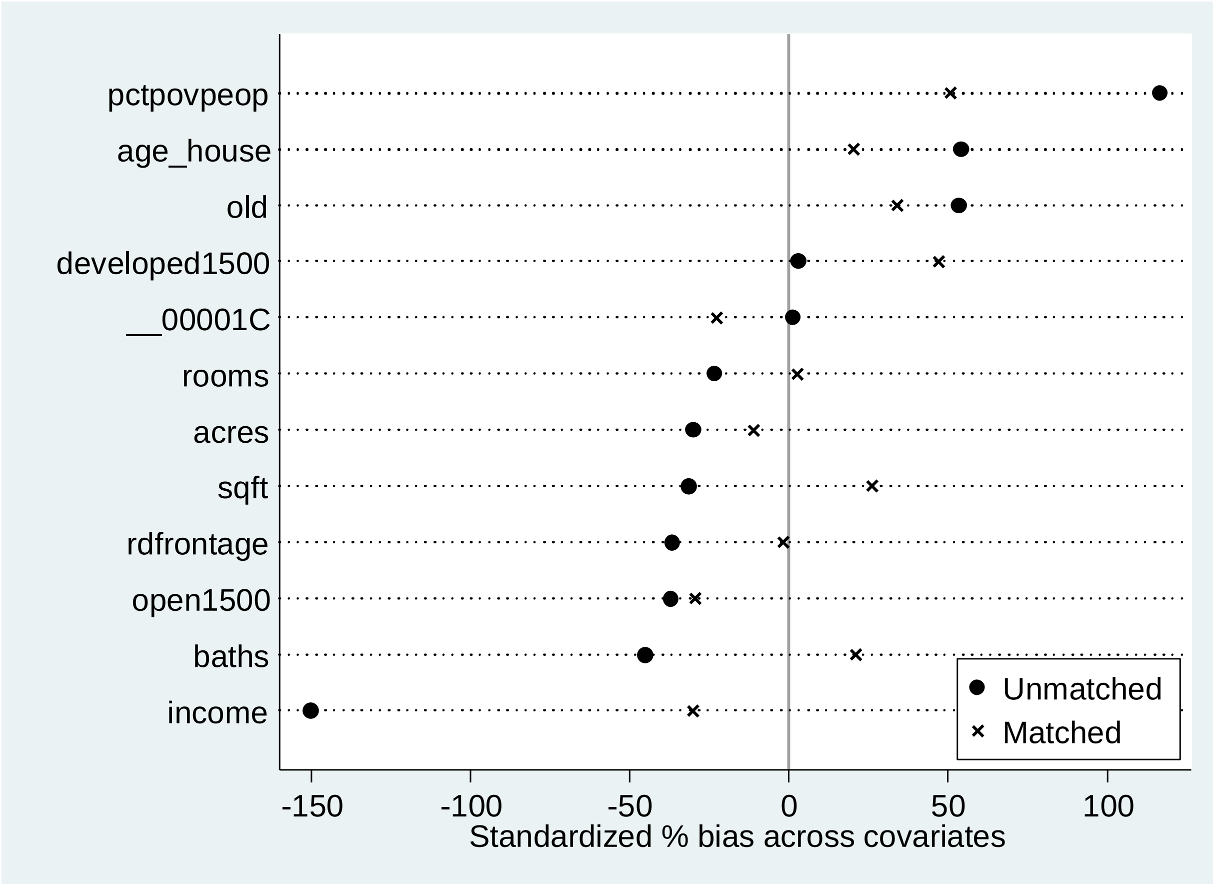

Figure A3. Standardized % Bias Before and After Matching: Great Works Dam

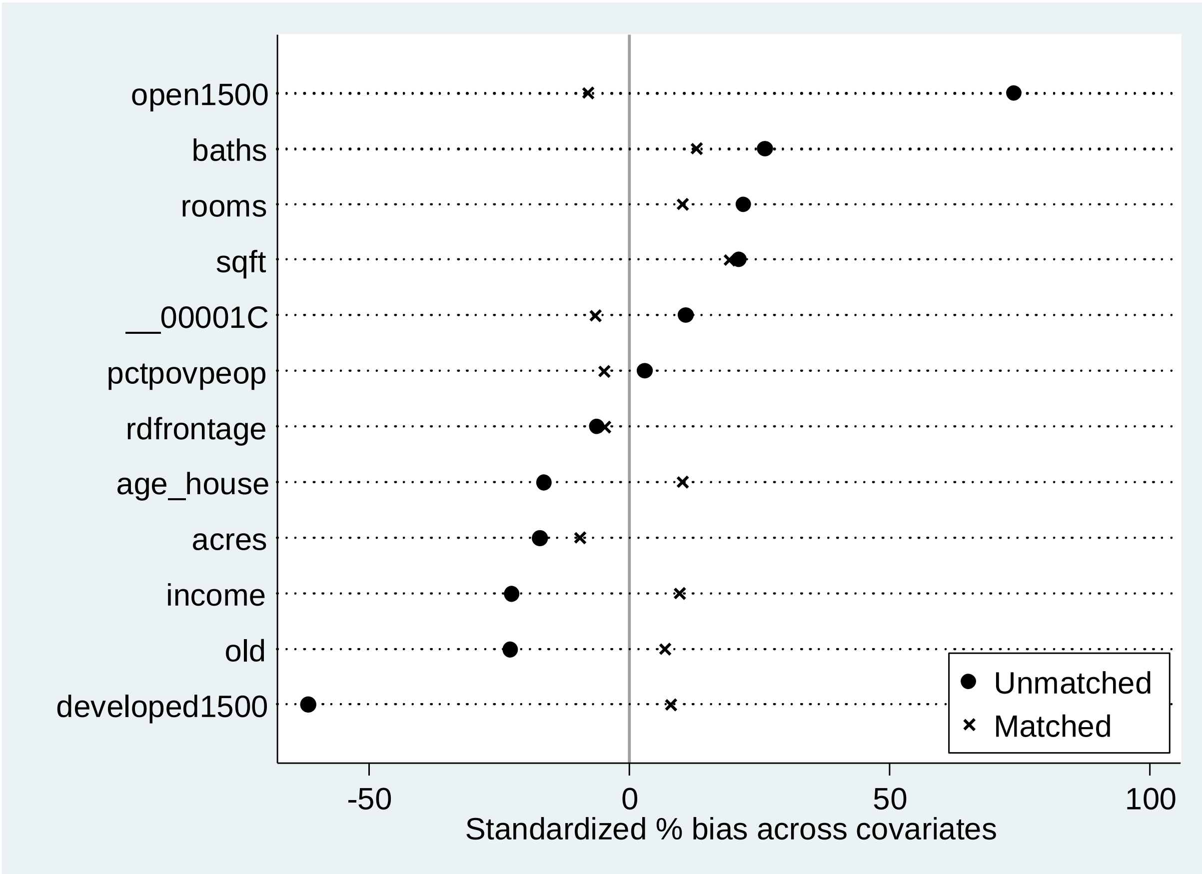

Figure A4. Standardized % Bias Before and After Matching: Veazie Dam