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Examining the economic impacts of hydropower dams on property values using GIS

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ABSTRACT

While the era of dam building is largely over in the United States, globally dams are still being proposed and constructed. The articles in this special issue consider many aspects and impacts of dams around the world. This paper examines dam removal and the measurement of the impacts of dams on local community property values. Valuable lessons may be found.

In the United States, hundreds of small hydropower dams will come up for relicensing in the coming decade. Whether or not the licensees are renewed and what happens to the dams if the licenses expires is a subject of great debate. Dams are beginning to be removed for river restoration and fisheries restoration and these "end-of-life" decisions may offer lessons for countries proposing or currently building small (and large) hydropower dams. What can these restoration stories tell us?

In this paper, we examine the effects of dams along the Penobscot River in Maine (USA) on residential property values. We compare the results to findings from a similar (but *ex post* dam removal) data set for properties along the Kennebec river in Maine, where the Edwards Dam was removed in 1999.

The Penobscot River Restoration Project, an ambitious basin-wide restoration effort, includes plans to remove two dams and decommission a third along the Penobscot River. Dam removal has significant effects on the local environment, and it is reasonable to anticipate that environmental changes will themselves be reflected in changes in property values. Here we examine historical real estate transaction data to examine whether landowners pay a premium or penalty to live near the Penobscot River or near a hydropower generating dam.

We find that waterfront landowners on the Penobscot or other water bodies in our study area pay approximately a 16% premium for the privilege of living on the water. Nevertheless, landowners pay LESS to live near the Penobscot River than they do to live further away, contrary to the expectation that bodies of water function as real estate amenities and boost local property values. Results with respect to the effect of proximity to hydropower generating plants are equivocal. Homeowners pay a small premium for houses close to hydropower dams in our region, but the statistical significance of that result depends on the specific model form used to estimate the effect.

Consideration of the social and economic impacts of dam removal-based river restoration can complement studies of the ecological impacts of the practice. Such studies help us understand the extent to which human society's subjective perception of value of aquatic ecosystems relates to objective measures of ecosystem health. The paper also illustrates how geographic information systems (GIS) can help inform these analyses.

1. Introduction

The US Army Corp of Engineers estimates that there are approximately 75,000 dams over six feet tall in the United States. Hundreds of thousands of smaller dams also block portions of rivers and create small impoundments. Many dams may provide valuable benefits, but at the same time dams cause negative impacts to rivers, to fish and wildlife and to local communities. While some dams may ultimately be removed to restore original uses of the river, others are removed for safety consideration. As dams age and as river values begin to attract attention, consideration of the future of many dams is at stake.

The era of dam building is essentially over in the United States. However, in other countries, dam building is on the agenda for many countries. While large dams have received considerable attention, very little research attention has been paid to smaller dams and especially small dams at the end of their lives. What is the economic impact of these dams and can these impacts offer any

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lessons? This paper provides evidence related to two cases in the State of Maine and we draw insights from those.

Maine has five major[1] and numerous minor rivers and streams that once provided significant habitat for endangered Atlantic salmon and other diadromous fishes. Over the past century and a half, settlement and industrialization along Maine's rivers led to discharges of sewage and mill wastes, extensive logging and use of the rivers for transportation of logs, as well as construction of dams for industrial and hydropower purposes. These activities degraded Maine's rivers, and led to declines in aquatic resources and increased problems with foam, odor and fish kills (e.g., Lichter et al., 2006; Saunders et al., 2006). By the mid 20th century, Maine's large rivers were blocked by dams, polluted and, for significant sections, aesthetically unappealing.

Recovery of Maine's rivers in recent decades has been substantial. The last log drives on Maine rivers were held in the early 1970s. Passage of the Federal Water Pollution Control Act (a.k.a., Clean Water Act) in the Early 1970s spurred tighter restrictions on industrial discharges and funded construction of sewage treatment facilities in Maine towns and cities. Stricter state water quality rules promulgated in the decades since have led to further reductions in discharges and subsequent improvements in water quality. Recreational use of Maine's rivers has increased as the public begins to see them not as eyesores, but as significant community assets.

Several recent efforts to restore Maine's rivers have targeted removal of dams that block migration of anadromous and catadromous fishes like commercially important alewives, the endangered Atlantic salmon, and American eel. The Edwards Dam in Augusta was removed from the head of tide in the Kennebec River in 1999, opening up nearly 20 miles of the Kennebec to migratory fishes. In 2006, the Madison Electric Dam on the Sandy River was removed. An agreement between environmentalists, regulators and the dam's owners to remove the Fort Halifax Dam in Waterville was tied up in legal wrangling for years as a result of determined local opposition. Fort Halifax dam was finally breached and removed in July of 2008. The Penobscot Restoration Project aims to remove two hydropower dams and decommission a third along the main stem of the Penobscot River.

The Penobscot River Restoration Project is a river-scale collaboration between NGOs, the Penobscot Tribe, state and federal government and hydropower interests. Project sponsors have recently executed a purchase option ($25 million $US) to buy dams from their current owners and begin decommissioning and removal. The project, if fully implemented, would lead to removal of the two lowermost dams on the Penobscot River, Veazie and Great Works, and the decommissioning of a third dam, Howland Dam, where an innovative bypass channel would be installed, permitting passage of fishes. Changes in management of other hydropower facilities in the watershed would maintain 95% of existing hydropower generation capacity along the river. The completed project, incorporating dam removal, construction of fishways, river restoration, and investments in river-front communities, is expected to cost on the order of $60 million, making it by far the largest environmental restoration effort in Maine. It is also an unprecedented example of multiple stakeholder negotiation and participation. This project offers some interesting lessons for other river basins.

Fig. 1 shows one of the Penobscot River Restoration Project Dams; Great Works.

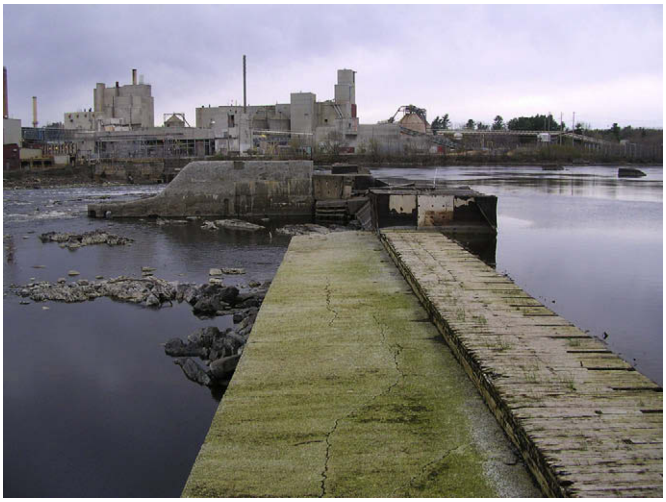

Fig. 1. Great Works Dam on the Penobscot River.

The Penobscot River supports the largest remaining population of wild Atlantic salmon in the United States. The Penobscot salmon population is of central importance to efforts to prevent extinction of Atlantic salmon in Maine (Fay et al., 2006). However, Atlantic salmon are only the most charismatic of New England's many diadromous fishes species, most of which have shown significant population declines in the past century (Saunders et al., 2006). Dams and other barriers to fish migration pose a significant threat to the continued survival of salmon and other diadromous fishes in these waters.

While dam removal may make environmental sense from the perspective of fisheries managers, it is often difficult to weigh conflicting social costs and benefits of dams and dam removal. The significance of these relationships and the extent to which they are (or are not) understood will become increasingly apparent as more and more dams outlive their useful lives, both in Maine and across the nation.

Economic assessments of the socio-economic impacts of dam construction or removal hinge on comparisons of welfare with and without the dam, an assessment that requires knowledge of human and environmental interactions both in the presence and absence of the dam. Such an assessment is difficult before a dam is constructed, as one can only speculate about how communities will respond to the dramatic landscape changes dams induce. Our existing understanding of how communities adapt to, and ultimately come to value dams and the changes in aquatic ecosystems they trigger is often not up to the task. The social and economic organization of communities near dams that have been in place for many years already reflect the presence of those dams. Paradoxically, an important way to improve our understanding of the economic and social effects of dams is to examine how communities value dams that are slated for demolition, like the ones on the Penobscot River, and to examine how communities respond to actual dam removals.

Only a few studies to date have carried out after-the-fact economic analyses of dam removals (Lewis et al., 2008; Provencher et al. (2008); Robbins and Lewis, 2008). Several recent publications emphasize the need for improved documentation and assessment of the socio-economic impacts of dam removal and river restoration (Maine State Planning Office, 2004; Johnson and Graber, 2002).

In this paper we use hedonic property value analyses to provide insight into how one group of stakeholders – property owners – value the Penobscot River and its associated hydropower facilities. We compare our findings to the findings of a recent retrospective study that examined the impact of dam removal on real estate values along Maine's Kennebec River.

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[1] Maine's five largest rivers are, from south to north, the Saco, Androscoggin, Kennebec, Penobscot, and St. Croix.

Hedonic property value analyses use market transactions to examine the contribution of property characteristics to sale prices and to gauge the underlying demand for these property characteristics (Palmquist, 1991). The theory of applying hedonic property models to conduct welfare analysis is well established (Freeman, 2003; Taylor, 2004; Young, 2005). The hedonic property value method is a revealed preference approach that utilizes data on real property transactions. Observed consumer purchases are used to indirectly estimate willingness to pay for an attribute. Hedonic models can include a wide range of information on the marketed properties, ranging from neighborhood socio-economic characteristics to structural features and environmental amenities and/or disamenities.[2]

The results of hedonic analysis capture only one component of societal values associated with dams and river characteristics. Nevertheless, this approach is important because it allows examination of how people's behavior – as measured in value of houses bought and sold – relates to potential environmental amenities and disamenities. People make their preferences clear through their behavior. Hedonic models allow us to determine whether or not changes in environmental quality are reflected in the housing market. Environmental economists have employed these models to assess the effects of a numerous environmental amenities (open space) and disamenities (air and water pollution, risks from superfund sites) on property values. This paper adds to this empirical literature by focusing on an under-studied subject (dams).

The empirical hedonic property value literature is extensive. A few studies, however, stand out in terms of relevance to this project. Leggett and Bockstael (2000) present a hedonic analysis of waterfront property with the *a priori* expectation that owners of waterfront property care about water quality as they have "essentially self-selected for an interest in water activity." Poor et al. (2001) examine and compare objective measures of water quality with subjective measures based on survey data on individuals' perceptions of quality. Poor et al. (2007) look at the value of ambient water quality within a hedonic study. Studies that have addressed questions of scale and patterns of land use include Bockstael (1996), Geoghegan et al. (1997), Acharya and Bennett (2001) and Bastian et al. (2002). Additionally, while a few studies have addressed the measurement of recreation and passive use values from dam removal (Loomis, 1996, 1999; Robbins and Lewis, 2008, for example) hedonic property value models have only recently been utilized in valuation for dams and dam removal explicitly using distance to a dam or dam site as potentially affecting property values (Lewis et al., 2008; Provencher et al., 2008).

2. Materials and methods

2.1. Study area

The Penobscot River watershed is located in Maine, USA, in a region of cool temperate to boreal climate. Mean annual precipitation is close to 1 m, spread evenly over the course of the year. Mean monthly temperatures vary from −10 °C to in the winter to +20 °C at the peak of the summer (NWS, 2007). Peak stream flows generally occur in the spring (March or April), due to snowmelt and high summer evapotranspiration. More than 120 dams are reported within the 8600 square mile Penobscot watershed (impounds data set from MEGIS, 2007), including 26 licensed hydropower facilities (Murch, 2007; Fig. 2). Fifteen major hydropower generating dams are located on the main stem of the Penobscot and its largest tributaries, the Stillwater, Piscataquis, West and East Penobscot Rivers.

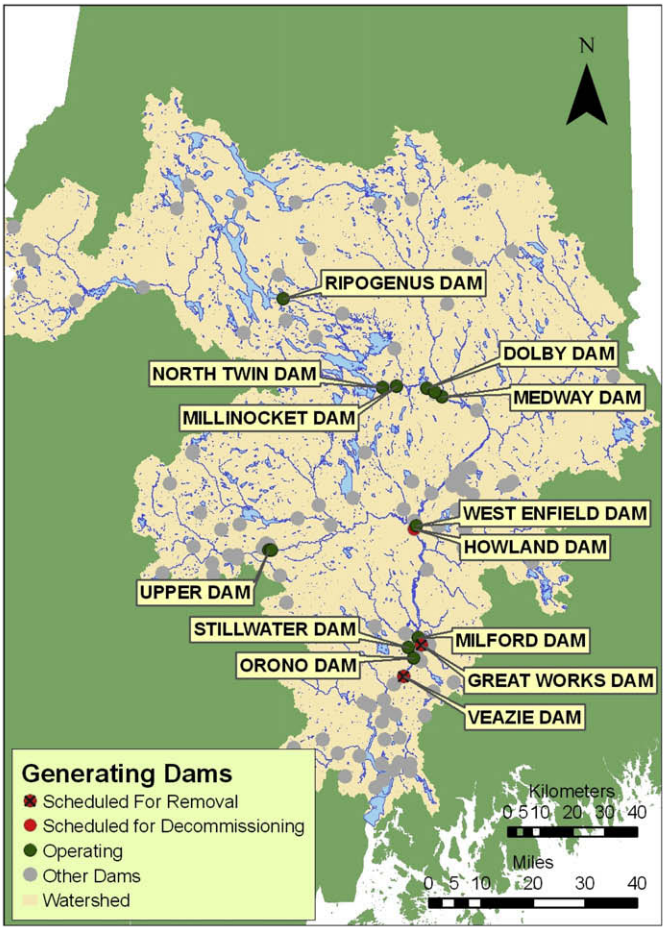

Fig. 2. Penobscot watershed dams.

Most of the watershed is sparsely populated, with large areas in industrial forest land. The largest city in the watershed is Bangor, near the southern end of the study area. The study area itself consisted of 20 townships within the Penobscot watershed and located near the Penobscot River, in areas adjacent to dams slated to be removed or decommissioned under the Penobscot Restoration Project. Townships included in the study stretched from the Bangor metropolitan area in the south to more sparsely populated Howland and Enfield to the north. Although the degree of urbanization varies markedly across the study area, the entire area is within reasonable commuting distance of Bangor, and forms a continuous real estate market.

2.2. Real estate sales data

We collected real estate transaction data on single family home sales that occurred between 1997 and 2006 from townships along the Penobscot River in Maine, USA.

Data on sales of houses were derived primarily from Multiple Listing Service records of real estate transactions. MLS data are coded by real estate agents at the time of listing of a house; data on sale date and sale price are added following the sale. The original data contains both coding errors and omissions. Obvious errors or internally inconsistent records were corrected or dropped from further analyses.

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[2] The theory underlying hedonic models was first developed by Griliches (1971) and Rosen (1974).

Our final data set includes information on slightly more than 7000 residential property sales that occurred during a period of 10 years from 1997 to 2006. The data included more than 1200 repeat sales. These sales occurred in 18 different townships (Fig. 3). Sales prices were adjusted to constant year 2000 dollars using deflators based on monthly Consumer Price Index values from the U.S. Bureau of Labor Statistics.

2.3. Geographic data

Geographic analyses were carried out in ArcGIS 9.1 and ArcView 3.2 (ESRI, Redlands, California, www.esri.com). We used GIS for a variety of purposes, including (1) to estimate locations of properties by geocoding, (2) to extract data on local economic conditions from U.S. census data, (3) to determine the distance between houses in the transactions data set and the Penobscot River and the hydropower dams, and (4) to calculate landscape metrics describing circular regions around each house.

Geographic location of houses was estimated by geocoding the addresses recorded in real estate transaction records by reference to Maine's enhanced 911 data. Enhanced 911 services enable emergency dispatchers to relate an emergency call to a specific location, thus speeding response. The geographic road and address data that makes this possible has been made public by the state of Maine (E911 data sets, MEGIS, 2007).

We used estimates of median household income and the proportion of the population living in poverty from the 2000 decennial U.S. census as indicators of economic conditions near the houses in our data set. Census data were downloaded in tabular form from the U.S. Census at www.census.gov. We used geographic data from MEGIS (2007) to relate the tabular data to physical locations at the Census Block Group level.

Data on the location of hydropower dams was compiled from several sources. A table of all active hydropower facilities in the state is available from the state Department of Environmental Protection (Murch, 2007). Active hydropower projects identified on that list were located by reference to an historical geographic data set of major dams and impoundments in Maine (impounds data set from MEGIS, 2007). Locations of hydropower dams within the study area were refined by reference to orthorectified aerial photographs, also made available by MEGIS (2007). We used GIS to calculate straight-line (Euclidean) distances between each property and the banks of the Penobscot River as shown in the wqrivers data set available from MEGIS (2007), as well as distances between each property and each of the hydropower dams.

Land cover data were derived from MELCD data, a raster data set based on 2003 satellite imagery (MEGIS, 2007). The data classify land cover into 23 different land use classifications within our study area. We simplified these to 13 land cover types.[3] Landscape metrics were calculated using the Spatial Analyst Extension in ArcGIS 9.1 and geoprocessing scripts written for ArcView 3.2. We calculated seven different land use metrics (Table 1), for circular regions of 405 m and 1500 m diameter around each property, giving us a total of 14 different landscape metrics.[4] (For a detailed description of the properties of the different diversity metrics, consult Magurran (1988), for a discussion of their use in the context of landscape analysis, see, for example, Gergel and Turner, 2002.)

2.4. Role of GIS

Use of geographic information systems (GIS) to inform economic analysis is a relatively recent addition to the economist's tool kit. GIS offers a powerful collection of tools for depicting and examining spatial relationships. Most simply, GIS can be used to produce compelling graphics that communicate the spatial structure of data and analytic results with force and clarity. But the technology's real value lies in the potential it brings to ask novel questions and enrich our understanding of social and economic processes by explicitly considering their spatial structure. Models that address environmental externalities have, almost by definition, a strong spatial component. Bateman et al. (2002) examine the contributions of GIS in incorporating spatial dimensions into economic analysis. Clapp et al. (1997) discuss the potential contributions GIS can make for urban and real estate economics.

Hedonic property analysis is fundamentally spatial in nature, and thus use of GIS in this context is a natural fit. Housing prices famously vary systematically and predictably from neighborhood to neighborhood. Spatially extensive properties that might influence property values, from air quality to the availability of open space, are strongly spatially structured; if one house enjoys abundant open space or especially good air quality, it is highly likely that its neighbors do as well. Interest in spatial analysis with hedonic property models is increasing as evidenced by the growing number of papers that incorporate spatial issues within hedonic property models (e.g., Cameron, 2006; Lewis and Acharya, 2006; Paterson and Boyle, 2002; Acharya and Bennett, 2001; Bell and Bockstael, 2000; Bockstael, 1996; Geoghegan et al., 1997).

In this context, GIS plays several roles. Housing transactions can be geo-coded, matching street addresses to specific geographic coordinates. Once transactions have been spatially located, widely available spatial data can be used to determine location-dependent properties of each house (vectors $\boldsymbol{N}$ and $\boldsymbol{Z}$ in equation (1), below). Location-dependent properties may be of direct interest to analysts (e.g., estimates of urban air quality, Anselin and Le Gallo, 2006, or distance to dams in the current study); or they may be proxies for anticipated spatial structure of housing markets (e.g., use of land cover metrics and median household income in this study). In the latter role, they function in a hedonic model as covariates, allowing the apparent impact of environmental externalities on property values to be corrected for urbanization, affluence of local neighborhoods, and other spatial phenomena.

2.5. Statistical analyses

Our complete data set incorporates ten descriptors of characteristics of individual houses, two descriptors of local economic conditions, fourteen variables describing local landscape conditions and measures of the distance of each house from the Penobscot River and from the nearest hydropower facility (Table 2).

Descriptive statistics of predictor variables are presented in Table 3. The typical house in our data set was over 50 years old, under 2000 square feet in size, and with 7 rooms. A majority of houses in the data set have only a single bathroom. Lot sizes (*acres*) are highly skewed, with most lots under 1/3 of an acre.

Slightly more than half the houses are located such that more than half of the land within a quarter mile is classified as open space (which includes some lawn area). Land cover surrounding houses tend to be diverse, with six or more of 13 possible land cover types represented within 1/4 mile of a majority of houses. In rural landscapes, diversity increases with increased development, as human-influenced land cover types are added to the mix. After a landscape reaches roughly 25% developed lands, further development leads to declines in landscape diversity. The lowest landscape diversity levels tend to occur in urban areas.

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[3] We aggregated to simplify interpretation and to enable comparisons in related work with two historic land cover data sets that used slightly different land cover classes. The aggregated land use classes include abandoned field/open land, agriculture, commercial forest, forest (non-wetland), wetlands, shores, other natural areas, grasslands/lawns, sparse residential, dense residential, urban/industrial, highways and water.

[4] The 405 m diameter was used for consistency with the resolution of older land use coverages that we investigated, but chose not to use in this study.

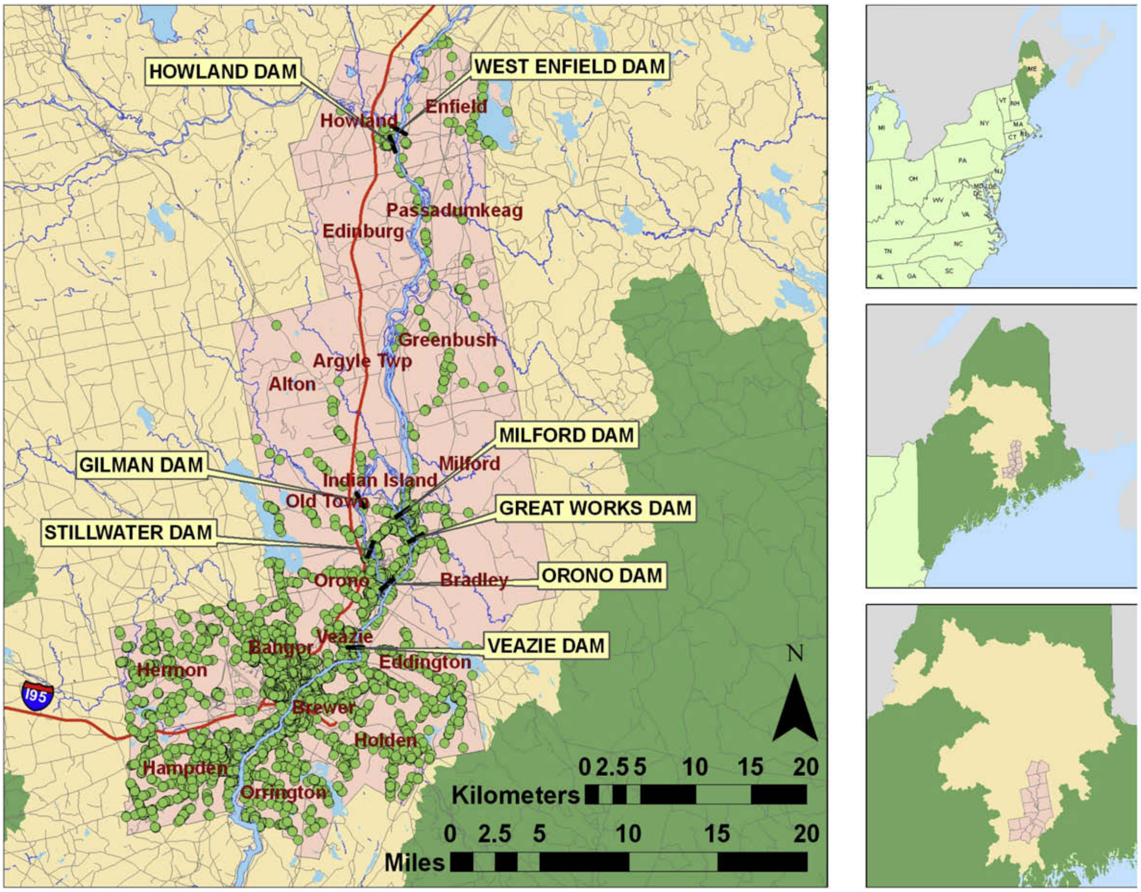

Fig. 3. Study area includes 20 townships in the Penobscot River watershed, Maine, USA. Green dots represent properties included in the real estate transaction data.

2.5.1. *Mathematical form of regression models*

In this paper, our main purpose is to examine whether the presence of rivers or hydropower dams influences nearby housing prices.

The hedonic function we estimate is as follows:

$$P_h = f_h\left(S_{h1},\ldots,S_{hj},N_{h1},\ldots,N_{hk},Z_{h1},\ldots,Z_{hm}\right) + \varepsilon \quad \text{for all } h \qquad (1)$$

where P_h is an observed market expenditure on housing (the price of house h). $\boldsymbol{S}$ is a vector of structural characteristics that describe the house, such as its size, number of rooms and so on; $\boldsymbol{N}$ is a vector of characteristics derived from U.S. census data that describe the neighborhood in which the house is located; and $\boldsymbol{Z}$ is a vector of locational and environmental characteristics derived from geospatial analyses. The final term, ε is a random error term. The hedonic price function (1) is therefore an implicit price relationship that gives the price of a house as a function of its various characteristics. The partial derivative of the hedonic price function with respect to any characteristic defined in (1) gives us the marginal implicit price of that characteristic. That is

$$\frac{\partial P_h}{\partial Z_j} = P_{hZ_j}\left(S_{h1},\ldots,S_{hj},N_{1k},\ldots,N_{hk},Z_{h1},\ldots,Z_{hm}\right) \qquad (2)$$

estimates a marginal implicit price for environmental variable Z_j.

Our focus here will be to examine the marginal implicit prices of (1) distance from the Penobscot or Stillwater Rivers and (2) distance from hydropower dams, as corrected for other characteristics of the houses that are also expected to influence housing prices.

The functional form of the hedonic price function is determined empirically. Preliminary analyses revealed strong heteroscedasticity in the data on the inflation-adjusted price of homes. Box–Cox analyses suggested that a cube root transform of the prices would result in maximum variance stabilization, but the cube root of housing prices offers no simple economic interpretation. A log transform reduces, but does not eliminate heteroscedasticity, but we have chosen to use it here because it offers a simple economic interpretation. Analysis based on the log of house prices has the convenient property that regression coefficients can be interpreted

Table 1
Landscape metrics calculated from land cover data. These were calculated at two spatial scales surrounding each house in the real estate transactions data.

Abbreviation	Description
PctDev	Proportion of developed land (sparse residential, dense residential, urban/industrial, and highways/runways) in a circular region centered on the house.
PctOpn	Proportion of open land (agriculture, commercial forest, other forest, wetlands, shores, other natural areas and grasslands/lawns) within the specified distance of the house.
PctWtr	Proportion of open water the specified distance of the house (since the three land use percentages exhaust all land use types, this is not independent of the last two metrics, but equals [1 − PctDev − PctOpen]).
H	Shannon diversity index. This index combines the number of land cover types and their relative evenness into a single index derived from information theory.
H_p	Shannon diversity index, scaled to take into account the number of land cover types observed. The result is often considered a measure of the "evenness" of the relative abundance of land covers observed.
C	Simpson diversity index. This index is more strongly influenced by the relative abundance of the most common land cover classes. It is often considered to reflect the degree to which land cover is dominated by a few land cover types.
S	Number of different land cover types observed. A simple, robust measure of landscape diversity.

Table 2
Variables examined for the analyses reported here.

Variable	Description	Role
town	Township	Components of vector ***S***
year_built	Reported year of house construction	
age	Year of sale minus reported year of house construction	
sqfeet	Size of the house in square feet above grade.	
rooms	Number or rooms reported for the dwelling	
bedrooms	Number of bedrooms	
bathrooms	Number of bathrooms	
fire_or_stove	Does the house have either a fireplace or a wood stove?	
acres	Size of lot, in acres.	
is_waterfr	House is reported as waterfront	
medhhinc	Median Household income in the census block in which the house is located.	Components of vector ***N***
proppov	Proportion of the population in poverty in the census block	
pctdev1500	Percent of developed land within 1500 m of the property	Components of vector ***Z*** (spatial covariates)
pctopn1500	Percent of open space within 1500 m	
pctwtr1500	Percent of open water within 1500	
h1500	Shannon Diversity index, on 1500 m circular region	
h_p1500	Shannon “evenness” index on 1500 m circle	
c1500	Simpson’s diversity index, on 1500 m circle	
s1500	Simple count of different land use types within 1500 m	
pctdev405	Developed land within 405 m	
pctopn405	Open land within 405 m	
pctwtr405	Percent of open water within 405 m	
h405	Shannon Diversity index, on 405 m circular region	
h_p405	Shannon “evenness” index on 405 m circle	
c405	Simpson’s diversity index, on 405 m circle	
s405	Simple count of different land use types within 405 m	
d_river	Distance to the Penobscot or Stillwater Rivers	Components of vector ***Z*** of primary interest
d_hydro	Distance to nearest hydropower generating dam.	
solddate	Date of final sale	Temporal and response variables
soldyear	Year of final sale	
soldmonth	Month of final sale	
soldprice	Actual sale price	
adj2000price	Sale price, adjusted using the monthly Consumer Price Index to constant 2000 dollars	
lnadjprice	Natural log of previous value	

in terms of the proportional change in housing price per unit change in the predictor variable. Results when analyses are carried using other transformations of the primary response variable are qualitatively similar to what we report here.

Model development proceeded as follows. First graphical data analysis methods were used to inspect the distributions of potential predictor variables and select suitable data transformations to normalize their distributions and linearize their relationship with the log of the inflation-adjusted home prices. Next, model selection proceeded step by step, first developing a statistical model for describing house prices based only on the vector ***S*** of structural characteristics of houses, then proceeding to develop a model that incorporated the neighborhood information and landscape metrics in vectors ***N*** and ***Z***. Only after these sub-models were fully specified did we examine models that directly incorporate distance from the river and distance from hydropower facilities (also part of vector ***Z***). At each step, variable selection proceeded based on economic intuition, stepwise model selection methods and informal model exploration. Final results were a compromise between statistical criteria and economic interest. All results, except as described below, were qualitatively robust to small changes in model form and in specific predictor variables used.

Graphical examination of the marginal distribution of the response variable (the natural log of the inflation-adjusted price, *lnadjprice*) as a function of potential predictor variables showed substantial non-linearities in the relationship between price and several predictor variables. In particular, response was strongly non-linear for the square feet of living space (*sqfeet*), the number of rooms in the house (*rooms*), the size of the lot in acres (*acres*) and the age of the house (*age*). Log transformation of the first three improved linearity of response so all analyses were carried out on log-transformed data for those predictors.

The relationship between the log-transformed, inflation-adjusted price of houses and the age of the house was more complex. Mean housing prices declined, as expected, with age for houses less than approximately 75 years, but then tended to level off. Such behavior can be approximated by a low-order polynomial regression, but it is more simply captured with a “broken stick” or segmented regression model (Faraway, 2005). A broken stick regression fits two straight lines constrained to be continuous at a single knot at an analyst-selected value of the predictor. Here, we placed the knot at age = 75 years. In effect, we fit separate but consistent regression relationships for houses less than 75 years and for houses greater than 75 years.

Due to high colinearity of landscape derived predictors, we chose to simplify our analyses by focusing on just one land use metric and one diversity metric at each spatial scale. We selected PctOpn for a measure of relative development, and Shannon’s *H* as a measure of landscape diversity.[5] Because we anticipate non-linearities in the relationship between housing prices and land use, we fit both a linear and quadratic terms for PctOpn.

Finally, for logical reasons, we expect that the effect of amenities or disamenities on housing prices should fall off non-linearly with distance. A 100 m increase in distance from the river would be expected to have a much larger effect on housing values if it means moving from 25 m to 125 m away from the river rather than if it means moving from 5000 to 5100 m from the river, where the effect is likely to be negligible. A number of functional forms could capture this behavior. We examined two functional forms in detail. First, we considered the relationship between housing prices and the natural log of distance from the river, which effectively makes the assumption that an equivalent percent change in distance from the river will have an equivalent effect on housing prices at all distances from the river. We also examined models that fit a relationship between housing prices and the inverse of distance, following Leggett and Bockstael (2000), Lewis and Acharya (2006), and Lewis et al. (2008).

Regression models were fit using both ordinary least squares and weighted least squares to account for heteroscedasticity. Results differed little, so only the ordinary least squares fits are reported here. We also explored whether the spatial structure of the data required use of full spatial statistical models. Empirical

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[5] This choice was motivated by both statistical and scientific criteria. PctDev and PctOpen are nearly linear combinations of each other (since open water is an uncommon land cover type, PctOpn $\sim$ 1 – PctDev). Including both terms in the model would exacerbate model instability. The choice of diversity metrics was based on widespread use of Shannon’s *H*, and its robust statistical properties compared to the alternatives.

Table 3
Descriptive statistics of predictor variables.

Variable	Mean	Standard deviation	Median	Minimum	Max.	*N*
year_built	1947.23	41.2873	1955	1775	2006	6914
age	59.72	41.079	52	1	232	6913
sqfeet	1709.0	727.36	1556	200	9000	4733
ln(sqfeet)	7.364	0.3940	7.350	5.298	9.105	4733
rooms	7.03	1.7805	7	2	18	7001
ln(rooms)	1.919	0.2492	1.946	0.693	2.890	7001
bedrooms	3.26	0.8317	3	1	9	7013
bathrooms	1.62	0.7107	1	1	5	6687
acres	1.56	5.5880	0.34	0.01	107	6861
ln(acres)	−0.726	1.2724	−1.079	−4.605	4.673	6861
medhhinc	41,068.01	11,972.2191	40,750	11,756	73,438	7036
proppov	0.11	0.0913	0.0787	0	0.534	7036
pctdev1500	0.327	0.2194	0.281	0.00261	0.737	7036
$(\text{pctdev1500})^2$	0.155	0.1609	0.079	6.81×10^{-6}	0.543	7036
pctopn1500	0.614	0.2192	0.624	0.196	0.987	7036
$(\text{pctopn1500})^2$	0.425	0.2715	0.389	0.0386	0.975	7036
pctwtr1500	0.058	0.0655	0.046	0	0.597	7036
$(\text{pctwtr1500})^2$	0.008	0.0200	0.002	0	0.357	7036
h1500	1.520	0.3126	1.568	0.465	2.203	7036
h_p1500	0.648	0.1108	0.658	0.212	0.870	7036
c1500	0.315	0.1126	0.295	0.128	0.820	7036
s1500	10.554	1.8344	11	4	13	7036
pctdev405	0.420	0.2624	0.379	0	0.975	7036
$(\text{pctdev405})^2$	0.245	0.2421	0.143	0	0.951	7036
pctopn405	0.541	0.2610	0.538	0.0214	1	7036
$(\text{pctopn405})^2$	0.361	0.2869	0.289	0.000458	1	7036
pctwtr405	0.039	0.0894	0.000	0	0.857	7036
$(\text{pctwtr405})^2$	0.009	0.0310	0.000	0	0.734	7036
h405	1.226	0.3538	1.221	0.12	2.219	7036
h_p405	0.734	0.1561	0.758	0.0875	1.000	7036
c405	0.378	0.1448	0.352	0.127	0.950	7036
s405	5.854	2.2166	6	2	12	7036
d_river	2408.04	2822.5	1289.53	8.25	15278	7036
(1/d_river)	0.001999	0.004102	0.000776	6.545×10^{-5}	0.1212	7036
ln(d_river)	7.086	1.2857	7.162	2.110	9.634	7036
d_hydro	7924.47	5314.9325	7147.13	163.45	25701.4	7036
(1/d_hydro)	0.000328	0.0005428	0.000140	3.891×10^{-5}	0.00612	7036
ln(d_hydro)	8.647	0.9646	8.874	5.096	10.154	7036
soldyear	2001.69	2.5360	2002	1997	2006	7036
soldmonth	63.14	30.0972	65	6	113	7036
soldprice	$123,391.4	$68,581	$110,000	$7,500	$700,000	7036
adj2000price	$130,384.1	$76,310	$113,629	$75,789	$775,184	7036
lnadjprice	11.62	0.5698	11.6407	8.933	13.560	7036

correlograms (Fig. 3) suggested that spatial statistical models were unnecessary, as simple multiple regression models that incorporated spatial predictor variables were able to account for almost all the spatial structure in housing prices. All statistical analyses were carried out in “R” (R Development Core Team, 2007).

3. Results

Table 4 presents the econometric regression results for the two models. Most predictors are significantly related to housing prices, but a few are not.

Structural characteristics of the house have expected signs. An additional room, for example, adds approximately 8% to value of a house (the effect is only marginally signific), while additional bathrooms add 13%. This is typical in Maine real estate. The age of houses has a significant effect on their price over roughly their first 75 years, but once houses have reached that age, there is little difference in the price of older homes.

Of particular interest for this paper are the spatial variables and the distance variables. The coefficient on the percentage of open space is positive and significant while the coefficient on the squared term is negative, suggesting diminishing returns to open space. Once land use within 1500 m of a home has been taken into consideration, relatively little additional information on housing price is added by considering land use within a smaller, 405 m radius.

Housing prices are significantly related to the distance between the house and the Penobscot River. While waterfront properties in our data set have significantly higher value than non-waterfront lands (positive parameter estimates for is_waterfr in both models, with significant *F* tests). Non-waterfront property owners do not pay a similar premium for being close to the River. In fact, housing prices are higher as you mover further from the river. A homeowner, on average, pays about 1.6% more for a house as its distance from the river increases by a factor of 2.

Comparisons between the two different models are illuminating. Prices are significantly affected by proximity to hydropower generating plants in the log-distance model, but not in the inverse distance model. The log-distance model suggests that the price of homes is slightly higher closer to hydropower facilities than at a distance; the inverse distance model reveals no such pattern.

Empirically, there is little to select one model over the other. However, the log-distance model embodies what we believe to be more reasonable assumptions about the way real estate prices behave with distance from the Penobscot. A graphical comparison of the two models is given in Fig. 4. The inverse distance model suggests that the costs associated with being near the river drop off rapidly, and that

Table 4
Parameter estimates for two regression models. Parameters for towns express deviations from the town of Alton, which functions here as a reference.

Log-distance model				Inverse distance model			
Variable	Estimate	Std. error		Variable	Estimate	Std. error	
Intercept	−174.50	3.0910	n/a	Intercept	−174.50	3.0970	n/a
Towns				Towns			
Alton	n/a			Alton	n/a		
Bangor	0.3088	0.0683	***	Bangor	0.3365	0.0682	***
Bradley	0.01083	0.0794		Bradley	0.09636	0.0774	
Brewer	0.280	0.0683	***	Brewer	0.288	0.0684	***
Eddington	0.0894	0.0718		Eddington	0.1319	0.0715	****
Edinburgh	−0.2447	0.1599		Edinburg	−0.2538	0.1596	
Enfield	−0.0311	0.0817		Enfield	−0.0019	0.0815	
Greenbush	−0.164	0.0801	*	Greenbush	−0.197	0.0799	*
Hampden	0.305	0.0681	***	Hampden	0.266	0.0678	***
Hermon	0.257	0.0691	***	Hermon	0.254	0.0689	***
Holden	0.248	0.0695	***	Holden	0.278	0.0695	***
Howland	−0.386	0.0845	***	Howland	−0.277	0.0829	***
Milford	0.0277	0.0741		Milford	0.1079	0.0724	
Old Town	0.136	0.0718	****	Old Town	0.221	0.0697	**
Orono	0.399	0.0713	***	Orono	0.474	0.0696	***
Orrington	0.256	0.0692	***	Orrington	0.221	0.0691	**
Passadumkeag	−0.216	0.0954	*	Passadumkeag	−0.233	0.0953	*
Veazie	0.335	0.0739	***	Veazie	0.422	0.0719	***
soldyear	0.092	0.0015	***	soldyear	0.092	0.0015	***
log(rooms)	0.6035	0.0234	***	log(rooms)	0.6043	0.0234	***
bedrooms	0.003	0.0065		bedrooms	0.004	0.0065	
bathrooms	0.136	0.0066	***	bathrooms	0.136	0.0066	***
log(acres)	0.1018	0.0047	***	log(acres)	0.1013	0.0047	***
(75 − age) for age < 75	0.0068	0.0002	***	(75 − age) for age < 75	0.0069	0.0002	***
(age − 75) for age > 75	0.0005	0.0002	*	(age − 75) for age > 75	0.0005	0.0002	*
fire_or_stove	0.1236	0.0084	***	fire_or_stove	0.1247	0.0084	***
Is_waterfr	0.1577	0.0184	***	is_waterfr	0.1533	0.0187	***
medhhinc	3.994×10^{-6}	5.345×10^{-7}	***	medhhinc	3.854×10^{-6}	5.346×10^{-7}	***
proppov	−0.223	0.0633	***	proppov	−0.210	0.0634	***
pctopn1500	1.002	0.1876	***	pctopn1500	1.033	0.1866	***
opnsp15sq	−1.125	0.1516	***	opnsp15sq	−1.091	0.1515	***
h1500	−0.106	0.0215	***	h1500	−0.092	0.0207	***
pctopn405	0.083	0.1007		pctopn405	0.056	0.1012	
opnsp4sq	−0.049	0.0947		opnsp4sq	−0.043	0.0950	
h405	0.0143	0.0168		h405	0.0130	0.0167	
log(d_hydro)	−0.0547	0.0113	***	1/(d_hydro)	0.5574	10.990	
log(d_river)	0.0251	0.0055	***	1/(d_river)	−2.4400	1.0240	*
$R^2 = 0.57$				$R^2 = 0.5719429$			
$F = 244.94$ on 35 and 6403 DF, $p \ll 10^{-6}$				$F = 244.44$ on 35 and 6403 DF, $p \ll 10^{-6}$			

Significance levels: $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$, $^{****}p < 0.10$.

the effect of distance to the river on house prices in negligible once you are more than a few hundred meters away from the river. The log-distance models show costs due to proximity to the river extending considerably farther, which we suspect is closer to the truth.

Fig. 5 depicts the predicted prices for the housing markets we investigated. We fixed the value of vector ***S*** in equation (1) so that it described a standardized non-waterfront houses that was 15 year old, had 4 bedrooms and 2 baths, and sold in 2000, and predicted housing prices at different locations across our study area based on the log-distance model. Higher prices in and around the Bangor metropolitan area dominate the pattern. Neighborhood economic conditions also play a large role. The effects of distance to the river and distance to hydropower generating plants, while statistically significant, are visually unimpressive at this scale.

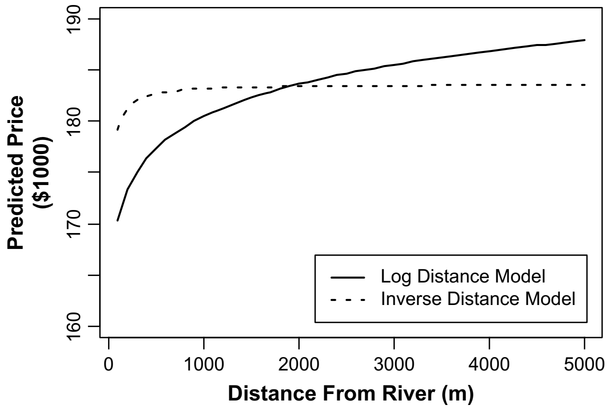

Fig. 4. Predicted housing prices as a function of distance from the Penobscot River based on two possible models.

Empirical correlograms (Fig. 6) reveal that the price of houses shows substantial spatial autocorrelation over distances up to about 500 m, and somewhat weaker autocorrelation out to a distance of about 3 km. In contrast, the residuals associated with the multiple regression models show almost no spatial autocorrelation, suggesting that the spatial structure in these data can largely be associated with predictor variables that themselves have significant spatial structure. The lack of a strong spatial component to the residuals suggests that results of a full spatial statistical model would be similar to that results of the analytically more tractable multiple regression models used here.

4. Discussion

4.1. Use of GIS in hedonic analysis

Models that address environmental externalities have, almost by definition, a strong spatial component. Moreover, hedonic

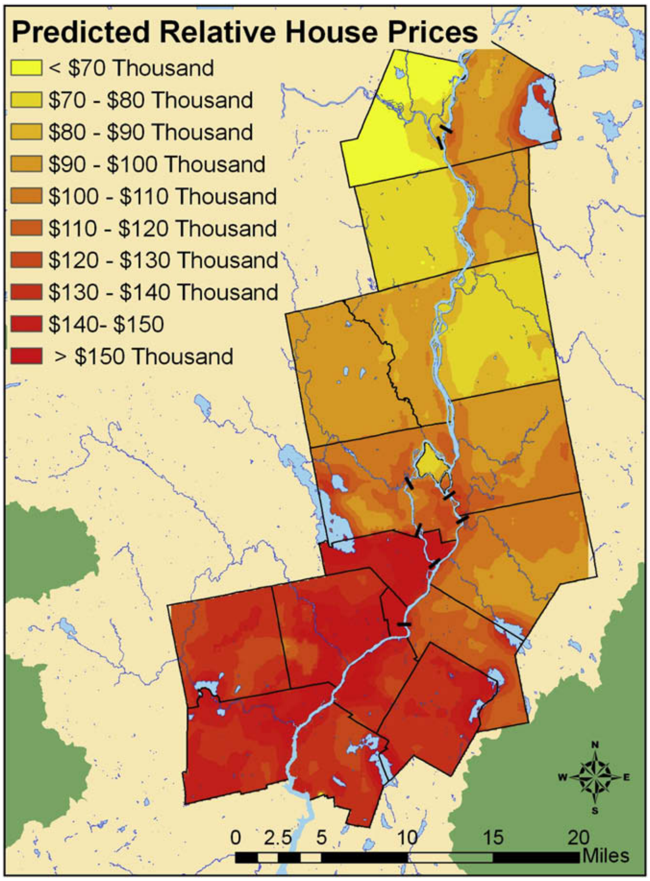

Fig. 5. Relative housing prices, as gauged by the estimated price for a 15 year old, 4 bedroom, 2 bath house sold in 2000.

property analysis is fundamentally spatial in nature, so use of GIS just makes sense. Housing prices vary predictably from neighborhood to neighborhood. Spatially extensive properties that might influence property values tend to be spatially structured. If one house enjoys the benefits of environmental amenities (or suffers from disamenities), it is likely that its neighbors do as well.

The power of GIS, in this context, lies in its ability to open these spatial patterns to investigation and permit testing of hypotheses about social, economic and historical processes that generate spatial patterns of value on the landscape. GIS permits non-geographic data on housing transactions to be geo-coded, matching street addresses to specific geographic coordinates.

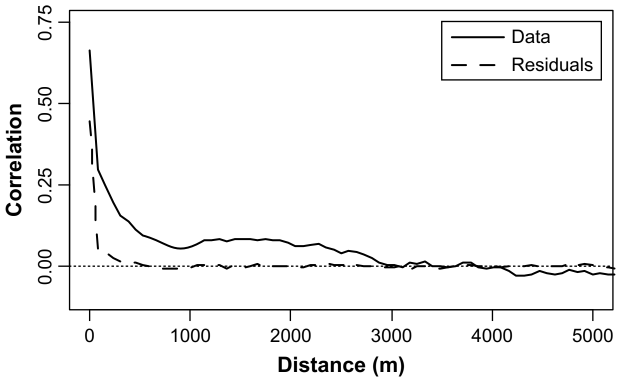

Fig. 6. Empirical correlograms.

For the Penobscot Project, GIS technology also allows us to visually examine our housing data with respect to the location of the dams and allows us to plot predicted prices based on location. This is a powerful predictive component that we can use to compare to our *ex post* study on the Kennebec.

4.2. Kennebec River study

This paper builds on a previous study of the economic values associated with the Kennebec River restoration and, in particular, the removal of the Edwards Dam in 1999.

The removal of the Edwards Dam in 1999 reopened for the first time in over 160 years nearly 22 miles of the Kennebec River to anadromous fishes. The removal led to rapid recovery of anadromous fish populations in the Kennebec and increased the value of recreational fisheries (Robbins and Lewis, 2008). The removal of the dam has been deemed a success by most observers based on evident improvements in biodiversity and ecosystem health.

The Edwards Dam removal represented the first time a functioning hydropower facility undergoing relicensing was removed with the goal of restoring aquatic ecosystems. In Lewis et al. (2008), we analyzed the net impact of the removal of the Edwards Dam on surrounding property values. We also estimated the impact of two remaining upstream dams on property values.

In that study, we found a penalty for living close to a dam site. Fig. 7 illustrates the effect of location, and in particular, distance to the dams on predicted property values. This figure illustrates the penalty for being close to a dam (which, in the case of the Edwards Dam, has declined since the dam was removed). Our results suggested that removal of Edwards Dam increased the values of nearby properties.

In the current study, we failed to find strong evidence for a similar negative impact of proximity to dams. It is not clear how to interpret this finding in the context of the planned Penobscot River Restoration Project. While we find little evidence that proximity to dams *per se* along the Penobscot acts as a disamenity, removal of the dams might still increase local property values, if removal contributed to restoration of rivers or if the disamenity value of dams has been masked in our analyses by confounding.

We did find a negative relationship between proximity to the Penobscot River and housing prices. This suggests that residents implicitly attribute negative value to proximity to the Penobscot River. While this finding may appear counter intuitive, it is in agreement with the results of the study on the Kennebec. Until quite recently, Maine's rivers were badly polluted, often smelled bad in the summer and offered few recreational opportunities. Local residents understandably placed little value in proximity to the river. Indeed, in many Maine river communities, the waterfront is dominated by graveyards and old mills. The grandest old houses are generally found uphill, away from the waterfront, while tenements were often constructed adjacent to the mills, and near the river.

Anecdotal evidence suggests that pattern may be changing. Maine's coastlines and lakes are already heavily developed. Real estate agents report increased interests in river-front properties. Moreover, the state's river-fronts are gaining official recognition as potential sites for commercial, residential, and community development. The Maine Legislature voted in the spring of 2007 to present a bond package to Maine voters that would, among other things, provide funds for community-based river-front development initiatives. The bond package was approved by voters in November of last year.

4.3. Implications for assessing dam impacts globally

Landscapes are highly structured both due to natural processes and because of human activity. Many spatial properties and

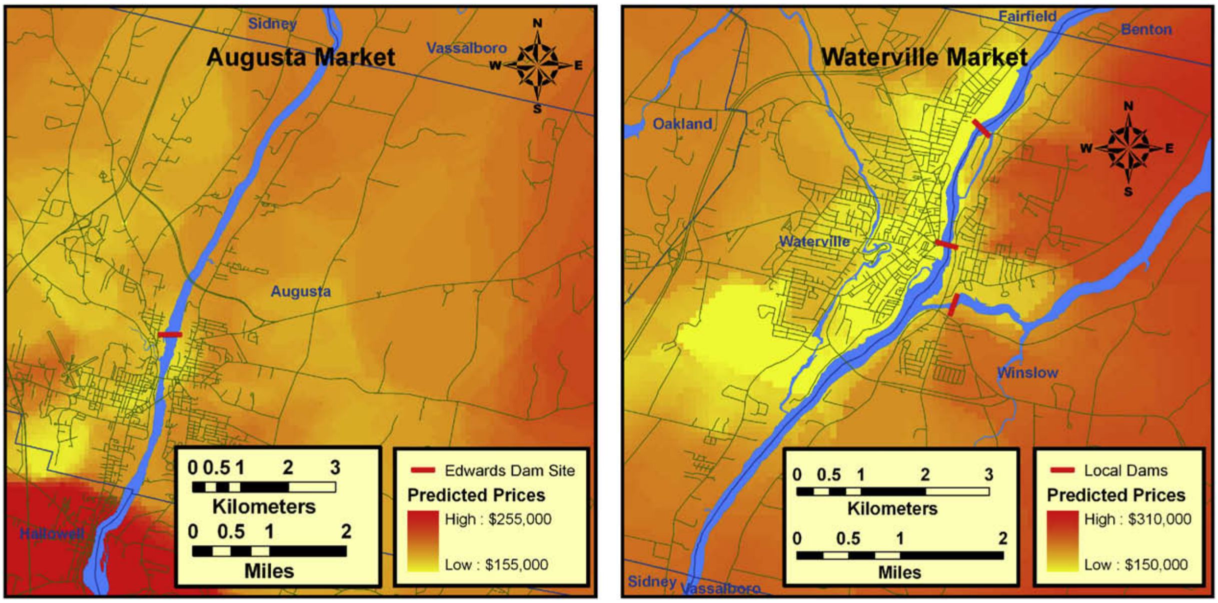

Fig. 7. Predicted property values for a standardized house in the Augusta Market near the former Edwards Dam site and in the Waterville market, near the current sites of the Lockwood, Fort Halifax, and Hydro Kennebec Dams.

landscape metrics vary in tandem, both because of geologic and ecological variation in landscape conditions and across the urban–rural gradient (McDonnell and Pickett, 1990). The result is that spatial information often contains much redundancy.

In the present case, proximity to dams is correlated with a number of features of the landscape. Since dams are located on rivers, if a house is close to a dam, it is, perforce, also close to a river, although the converse is not true (Fig. 8a). Sites in Maine suitable for modern hydropower development were generally also suitable for earlier water powered technologies. Dams to power grist, saw, or textile mills often stood at the locations now occupied by hydropower dams. Such sites often formed the nucleus of communities, and now, several generations later, are found at the center of urban areas. Houses in urban landscapes are on average closer to dams than rural houses (Fig. 8b).

Given the highly structured nature of landscapes, it will often be difficult to determine just what features of the landscape are, in fact, being valued by home buyers when they pay a premium for houses located in certain locations. Does an observed negative relationship between housing prices and proximity to rivers mean that residents do not wish to live near rivers, or only that the housing near rivers has other undesirable characteristics? Lewis et al. (2008) were able to capitalize on the recent removal of the Edwards Dam on the Kennebec to search for changes in valuation of lands, helping to make the case that, at least in that case, dam removal provided benefits to home owners. In an *ex ante* analysis such as this one, we do not have that luxury.

Dams fundamentally alter the local environment and shift relationships between humans and aquatic ecosystems, potentially imposing significant costs at the time of their construction. But over time, communities learn to take advantage of the environmental conditions the dams produce. People and communities buy land adjacent to reservoirs, build parks, invest in boats or equipment to exploit the opportunities dams induce or build in floodplains once too flood-prone to be attractive sites for investment. Dams and reservoirs become part of the physical infrastructure of communities. It should come as no surprise therefore, that dam removal is often controversial.

Revealed preference methods such as the hedonic valuation method offer a way to measure the impacts that attributes – like

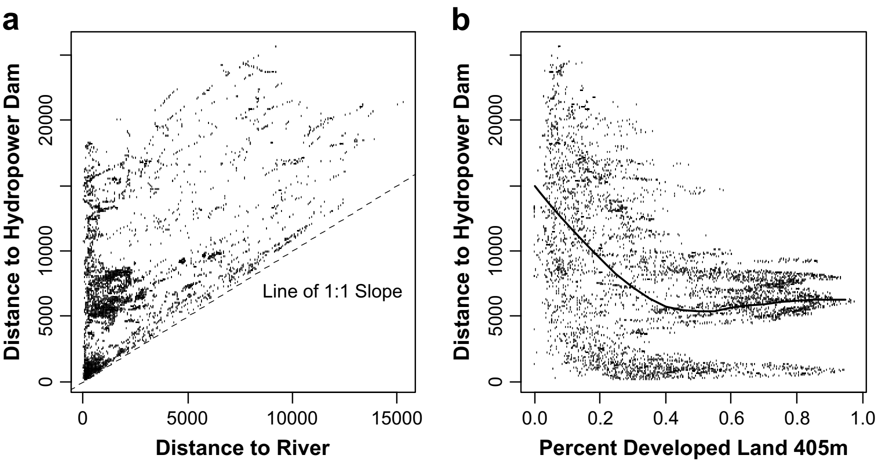

Fig. 8. Distance to hydropower dams varies systematically with other landscape metrics.

dams – have on property values. This method has proven extremely useful in areas with well-defined property rights. For many countries, however, property rights are not well defined and measuring the impacts would be more difficult. GIS, however, can help. Visualization of house locations combined with other geographical and socio-economic information can enhance our ability to assess dam impacts on neighboring communities.

Decisions to build these dams were not based on any "end-of-life" considerations, nor were instream values taken into account. For those cases where those values have come to alter previous decisions such that dams are being or might be removed offers valuable lessons globally. Are these decisions irreversible?

The computational, geographic, conceptual and statistical tools to enable researchers to examine how and to what extent communities value dams, reservoirs and rivers have only recently become available. Empirical research on the relationship between communities and dams remains rare. Yet the need for robust socio-economic analysis of the impacts of dams, dam construction, and dam removal has never been greater.

4.4. *Conclusions*

The World Commission on Dams (2000) reports five key points related to dam building in their report on Dams and Development. These are:

- "Dams have made an important and significant contribution to human development, and the benefits derived from them have been considerable.
- In too many cases, an unacceptable and often unnecessary price has been paid to secure those benefits, especially in social and environmental terms, by people displaced, by communities downstream, by taxpayers and by the natural environment.
- Lack of equity in the distribution of benefits has called into question the value of many dams…
- By bringing to the table all those whose rights are involved and who bear the risks associated with different options for water and energy development, the conditions for a positive resolution of competing interests and conflicts are created.
- Negotiating outcomes will greatly improve the development effectiveness of water and energy projects by eliminating unfavorable projects at an early stage and by offering as a choice only those options that key stakeholders agree represent the best ones to meet the needs in question."[6]

The Penobscot River Restoration Agreement offers a model for stakeholder participation that is unprecedented. The agreement was negotiated among and signed by the Federal Government, The State of Maine, The Penobscot Indian Nation, Pennsylvania Power and Light (owner of the dam) and a coalition of environmental groups interested in river restoration. This agreement is considered win–win by all involved. This paper examines the impact of these dams on community property values. As the Penobscot River Restoration Project moves forward, there may be additional valuable lessons.

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References

Acharya, G., Bennett, L.L., 2001. Valuing open space and land use patterns in urban watersheds. Journal of Real Estate Finance and Economics 22 (2/3), 221–237.

Anselin, L., Le Gallo, J., 2006. Interpolation of air quality measures in hedonic house price models: spatial aspects. SAL Working Paper. January 9, 2006. Available from: <http://www.sal.uiuc.edu/stuff/stuff-sum/pdf/hedonic.pdf>.

Bastian, C.T., McLeod, D.M., Gerino, M.J., Reiners, W.A., Blasko, B.J., 2002. Environmental amenities and agricultural land values: a hedonic model using geographic information systems data. Ecological Economics 40 (3), 337–349.

Bateman, I.J., Jones, A.P., Lovett, A.A., Lake, I.R., Day, B.H., 2002. Applying GIS to environmental and resource economics. Environmental and Resource Economics 22, 219–269.

Bell, K.P., Bockstael, N.E., 2000. Applying the generalized method of moments approach to spatial problems involving micro-level data. Review of Economic and Statistics 82 (1), 72–82.

Bockstael, N.E., 1996. Economics and ecological modeling: the importance of a spatial perspective. American Journal of Agricultural Economics, 1168–1180.

Cameron, T.A., 2006. Directional heterogeneity in distance profiles in hedonic property value models. Journal of Environmental Economics and Management 51, 26–45.

Clapp, J.M., Rodriguez, M., Thrall, G., 1997. How GIS can put urban economic modeling on the map. Journal of Housing Economics 6, 368–386.

Faraway, J.J., 2005. Linear Models with R. Chapman Hall, New York.

Fay, C., Bartron, M., Craig, S., Hecht, A., Pruden, J., Saunders, R., Sheehan, T., Trial, J., 2006. Status Review for Anadromous Atlantic Salmon (Salmo salar) in the United States. Report to the National Marine Fisheries Service and U.S. Fish and Wildlife Service. 294 pp. Available from: <http://www.nmfs.noaa.gov/pr/pdfs/statusreviews/atlanticsalmon.pdf>.

Freeman, A.M., 2003. The measurement of environmental and resource values: theory and methods. Resources for the Future, second ed.

Geoghegan, J., Wainger, L.A., Bockstael, N.E., 1997. Spatial landscape indices in a hedonic framework: an ecological economics analysis using GIS. Ecological Economics 23, 251–264.

Gergel, S.E., Turner, M.G., 2002. Learning Landscape Ecology: a Practical Guide to Concepts and Techniques. Springer, New York.

Griliches, Z. (Ed.), 1971. Price Indexes and Quality Changes. MA. Harvard University Press, Cambridge.

Johnson, S.E., Graber, B.E., 2002. Enlisting the social sciences in decisions about dam removal. Bioscience 52 (8), 731–738.

Leggett, C.G., Bockstael, N.E., 2000. Evidence of the effects of water quality on residential land prices. Journal of Environmental Economics and Management 39 (2), 121–144.

Lewis, L., Acharya, G., 2006. Environmental quality and housing markets: does lot size matter? Marine Resource Economics 21, 317–330.

Lewis, L., Bohlen, C., Wilson, S., 2008. Dams, dam removal and river restoration: a hedonic property value analysis. April. Contemporary Economic Policy 26 (2), 175–186.

Lichter, J., Caron, H., Pasakarnis, T.S., Rodgers, S.L., Squires Jr., T.S., Todd, C.S., 2006. The ecological collapse and partial recovery of a freshwater tidal ecosystem. Northeastern Naturalist 13 (2), 153–178.

Loomis, J., 1996. Measuring the economic benefits of removing dams and restoring the Elwha River: results of a contingent valuation survey. Water Resources Research 32 (2), 411–447.

Loomis, J.B., 1999. Recreation and Passive Use Values from Removing the Dams on the Lower Snake River to Increase Salmon. A Report to the Walla Walla, Washington District of the U.S. Army Corps of Engineers. Available from: <http://www.nww.usace.army.mil/lsr/reports/rec_passive/pass_rec.htm>.

Available from: Maine Office of Geographic Information Systems (MEGIS), 2007. Maine Geographic Information System <http://megis.maine.gov>.

Available from: Maine State Planning Office, 2004. Draft Maine River Restoration User Guide <http://www.maineenergyinfo.com/docs/ExploringRiverRestorationReport.doc>.

Magurran, Anne E., 1988. Ecological Diversity and its Measurement. Princeton University Press, Princeton, NJ.

McDonnell, M.J., Pickett, S.T.A., 1990. The study of ecosystem structure and function along urban–rural gradients: an unexploited opportunity for ecology. Ecology 71, 1231–1237.

Available from: Murch, Dana, 2007. Hydropower Projects In Maine. Maine Department of Environmental Protection. DEPLW0363-G2007 <http://www.maine.gov/dep/blwq/docstand/dams/hydroprojectreport.pdf>.

Available from: National Weather Service (NWS), 2007. NWS Caribou, ME Climate Data <http://www.weather.gov/climate/xmacis.php?wfo=car>.

Palmquist, R., 1991. Hedonic methods. In: Braden, J.B., Kolstad, C.D. (Eds.), Measuring the Demand for Environmental Quality. Elsevier, North-Holland, New York.

Paterson, R.W., Boyle, K.J., 2002. Out of sight, out of mind? Using GIS to incorporate visibility in hedonic property value models. Land Economics 78 (3), 417–425.

---

[6] World Commission on Dams, Dams and Development: A New Framework for Decision Making: The Report of the World Commission on Dams, November. 2000. Available from: www.dams.org, p. 3.

Poor, P.J., Boyle, K.J., Taylor, L.O., Bouchard, R., 2001. Objective versus subjective measures of water clarity in hedonic property value models. Land Economics 77 (4), 482–493.

Poor, P.J., Pessagno, K.L., Paul, R.W., 2007. Exploring the hedonic value of ambient water quality: a local watershed-based study. Ecological Economics 60 (4), 2007.

Provencher, W., Sarakinos, H., Meyer, T., 2008. Does small dam removal affect local property values? An empirical analysis. Contemporary Economic Policy 26 (2), 187–197.

Available from: R Development Core Team, 2007. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0 <http://www.R-project.org>.

Robbins, J., Lewis, L., December 2008. Demolish it and they will come: dam removal and the *ex-post*measurement of fisheries benefits. Journal of the American Water Resources Association 44 (6).

Rosen, S., 1974. Hedonic prices and implicit markets: product differentiation in perfect competition. Journal of Political Economy 82 (1), 34–55.

Saunders, R., Hachey, M.A., Fay, C.W., 2006. Maine's diadromous fish community: past, present, and implications for Atlantic salmon recovery. Fisheries 31 (11), 537–547.

Taylor, L.O., 2004. The hedonic method. In: Champ, P., Boyle, K.J., Brown, T.C. (Eds.), A Primer on Non-Market Valuation. Kluwer Academic Publishers, London, pp. 331–394.

Young, R., 2005. Determining the economic value of water. Resources for the Future.