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Environmental restoration offsets population decline in postindustrial communities

Jeremy G. Weber[1*], Shawn McCoy[2], Katie Jo Black[3], Max Harleman[4]

Abstract

Can turning an environmental hazard into an amenity help sustain communities facing industrial and population decline? We study Pennsylvania coal communities over three decades, estimating how mine-impaired waterways and their restoration affected population growth as mining and manufacturing declined regionally. We find that communities with mine-impaired waterways and no restoration had 4 percentage points less population growth than similar nearby communities, leading to depopulation for many. Even partial restoration offset this effect, with growth driven by college-educated individuals and those age 65 and older. The presence of mine water treatment systems, usually a series of wetlands and ponds, did not affect population growth apart from effects on water quality. In the face of major economic transitions, environmental restoration can help communities retain and attract residents, thereby advancing the goals of traditional place-based economic development incentives.

Keywords: Mine Drainage, Amenities, Population, Coal, GIS, Pollution Mitigation

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1 Introduction

Local economies can struggle to recover from declines in key industries [1]. In some instances, distressed firms in withering industries can leave behind decrepit infrastructure or environmental contamination that may stymie revitalization efforts because of the large societal cost they can impose. This is potentially the case for many communities in the Appalachian region of the United States, where drainage from abandoned coal mines burdens communities by making waterways unsuitable for fish and unsafe for swimmers [2]. Looking over 1990-2020, we study how mine pollution affected the ability of communities to attract residents and visitors as key industries declined. Over the period, mining counties in our study-state of Pennsylvania saw coal and non-mining manufacturing employment decline by 63 and 32 percent, respectively. Both industries also experienced nationwide declines [3, 4] (Figure S1).

Prior research provides theory and evidence on how legacy pollution could hinder economic revitalization. People avoid polluted areas or require compensation through lower housing costs to live near them [5, 6]. Conversely, they are attracted to areas with scenic views and recreational amenities and will to accept lower wages or higher housing costs for them [7, 8]. Treating mine drainage pollution could leverage both tendencies by transforming waterways from a hazard to avoid into an amenity to enjoy [9]. The transformation restores a broadly accessible public good, which can be repeatedly enjoyed by many, especially in states like Pennsylvania that give the public the right to use waterways for fishing or kayaking[10].

Beyond direct health and recreational benefits, restoring visibly polluted waterways could have broad social and psychological effects. Pollution could signal neglect of a community, creating a "broken window" effect that reduces investment, property values, the tax base, and public services [11, 12]. This aligns with findings that surface water quality improvements increase housing values well beyond those with direct access to the water [13, 14]. By turning a signal of neglect into one of care and renewal, restoration could shift pessimistic perceptions of decline to optimistic expectations of improving quality of life.

Improving environmental quality or amenities could have large and enduring effects on local economies, especially more rural ones. Without countervailing forces, population losses from mine closures and environmental degradation could precipitate an unwinding of rural economies as local governments, hospitals, and utilities attempt to support the same infrastructure with fewer users. Rising tax and utility rates, coupled with hospital closures would amplify initial losses, perhaps over decades. For example, counties that experienced the most soil erosion in the 1930's dust bowl saw their relative population decline until 1960, and as of 1990, they had not regained any population relative to less affected counties [15]. In such contexts, retaining residents or attracting new ones can undergird a local economy by stabilizing property values and public services that preserve community viability.

Investing in environmental quality and natural amenities is not usually cast as economic development policy, yet it could advance similar goals while directly benefiting residents. Traditional policies, such as tax or cash incentives to attract firms or workers, can be costly, bypass distressed areas, or lack positive long-term effects [16, 17]. More recent policies suggest growing recognition of amenities' role in location

decisions. West Virginia offers cash incentives plus one year of free access to outdoor activities for those who relocate there [18, 19], implicitly acknowledging what research confirms: migrants are attracted by amenities nearly as often as by low taxes [20]. In this way, amenities help firms meet labor needs and create new business opportunities in recreation and tourism.

To examine the effects of legacy waterway pollution on community economies, we construct census-tract measures of initial impairment and subsequent restoration. This yields two complementary tests. First, do tracts with initially impaired waterways experience slower population growth than tracts with no mine-impaired waterways? And second, does restoration in impaired tracts accelerate growth relative to similar tracts with impairment but no restoration? We address four key confounding factors through county fixed-effects (which absorb regional economic shocks), tract-level initial mining employment (which captures localized industry decline), the location of treatment systems (which helps account for potential endogeneity of restoration decisions and any direct effects of treatment spending), and tract-level social capital measures (which account for differences in capital correlated with restoration and growth). Further, decomposing population changes by education and age reveals which subgroup may drive any effects. We also test whether impairment and restoration affect visits from nonresidents as measured by short-term rental listings and revenue, both for all properties and the subset that explicitly advertises water amenities.

2 Results

As of 1990, an estimated 525 census tracts in Pennsylvania had a waterway impaired by mine drainage (Figure 1a). Over the subsequent three decades, nearly half of them had some waterways restored, which are those whose pollution loads would have exceed regulatory thresholds in the absence of upstream treatment systems [21]. Restoration occurred throughout all regions of the state with initial impairment (Figure 1b, Figure 2, Table S1). Over the same period, many tracts, especially those in Western and Northern Pennsylvania lost population (Figure 1c).

More population loss occurred in places with mine-impaired waterways. We run our base empirical model (Equation 1) on a sample of 1,756 census tracts in Pennsylvania counties with at least some impairment as of 1990. It shows that over the 1990-2020 period tracts with some impaired waterways (and no restoration) had 8.4 percentage points less population growth, as indicated by the coefficient on the impaired indicator (Figure 3 and Table 1, column 1). Because the average sample tract grew by only 1.4 percent over the period (Table S1), impairment pushed some tracts into depopulation. Having some of the impaired waterways restored more than offset the depopulation effect, with remediation associated with 8.3 percentage points in greater growth.

Some but not all of the unconditional differences population growth stem from different baseline socioeconomic conditions, such as greater initial unemployment. Controlling for initial conditions reduces the impairment coefficient by one half, to -4.3 percentage points (95% CI: -7.4 to -1.4)), and the restoration coefficient by one quarter, to 6.0 percentage points (95% CI: 1.5 to 10.5), thus still indicating that restoration can undo the depopulating effects of impairment (Figure 3 and Table 1, column 4). All of the results to follow include controls for baseline socioeconomic conditions.

When controlling for waterway status, treatment systems themselves had no clear effect population growth, with a less than one percentage point difference in growth between tracts with and without systems. Thus, their value to communities depends on them yielding tangible improvements in waterway quality. Separating the effect of systems from their downstream effects is possible because less than one-third of tracts with restored waterways hosted a treatment system (Table S1). This highlights how the effects of treatment can extend far beyond the tract where treatment occurs.

Treatment system construction and changes in waterway impairment status occurred consistently throughout the 30-year study period. To see if the effects are unique to a period, we estimate the model separately for each of the three decades (1990-2000, 2000-2010, and 2010-2020). The estimates show that restoration is consistently associated with higher growth and impairment with lower growth (Figure S2, Table S2), with the point estimates for restoration are always about +1 to +3 percentage points, and those for impairment always below -1 percentage point.

Estimating the marginal effects for miles of waterways (unimpaired, impaired, and restored) suggests that more impairment means less population growth on average (Table 1, columns 2 and 3), though the estimate is only statistically different from zero when not controlling for baseline demographics. The coefficients on miles impaired and miles restored are of a similar order of magnitude and with the expected sign: negative for miles impaired and positive for miles restored. The effect of miles restored is the least precisely estimated, likely reflecting greater error in measuring the exact extent of water quality improvements.

2.1 Effects by Education and Age

Estimates show that impairment suppresses growth in the college-educated population (-5 p.p.) (Figure 4a and Table S3, column 5) and marginally increases the population of those with at most a high school education. In contrast, restoration most spurs growth in the college-educated population (+10 p.p.) and has increasingly smaller effects as educational attainment declines. The difference in estimates is striking, with the positive effect of restoration on the college educated twice as large as the negative effect of impairment on the same group. This suggests that tracts with restoration gain college-educated population relative to impaired tracts, and even relative to tracts with no mine-impaired waterways.

Estimates by age group show impairment causing a 3 to 5 percentage point drop in population growth across all adult age groups (Figure 4b and Table S4). By contrast, restoration increases population among all groups and especially for those 65 and older or between 18-24, with growth effects of 11 and 6 percentage points, respectively. One interpretation is that restoration encourages existing residents to retire in place or it attracts retirees looking for an affordable and amenity-rich community.

2.2 Comparable and Complementary Amenities? Multi-Use Trails

We add to our main empirical model an indicator for whether the tract has a public multi-use trail (biking, hiking, running), most of which opened since 1990 when Pennsylvania passed a Rails-to-Trails Act [22]. We also interact the trail indicator with the restoration indicator to see if trails amplify the effect of restoration. Having a trail led to a 4.3 percentage point increase in growth (Table S5, column 4), and the effect is statistically similar for tracts with or without restoration. This means that areas with restoration and trails had greater population growth than those with only trails or only restoration, but restoration did not increase the trail effect itself.

Similarity in the magnitudes of the effects of trails, impairment, and restoration lends credibility to our estimates. Trails and waterways are public goods that foster outdoor recreation and can be enjoyed repeatedly. It is plausible that adding a multi-use trail affects population growth similar to restoring a waterway from mine impairment, and that both can offset the negative effect of an impaired waterway.

2.3 Social Capital and Restoration

The negative effects of impairment and the positive of restoration could reflect a correlation between these variables and the social capital of a community. For the subsample of tracts with social capital data, sequentially adding variables for economic connectedness and civic engagement does not affect the coefficients for impairment or restoration (Table S6). This is noteworthy because economic connectedness, which is a strong predictor of individual upward income mobility [23], is also a strong predictor of population growth in our sample and time frame. Because adding the variable had no effect on the coefficients of our key variables, economic connectedness is uncorrelated with impairment or restoration status conditional on the other control variables.

2.4 Restoration and Short-Term Rental Activity

If polluted waterways make a tract less attractive as a place to live, it may also make it less attractive as a place to visit and recreate. We find suggestive evidence of this by analyzing data on the number and gross revenue of short-term rental properties in a tract. When looking at all types of short-term rentals, impairment is associated with a 62 percent decrease in short-term rentals (Table S7). [1] The coefficient on restoration is positive but smaller and imprecisely estimated. When looking at only rentals that highlight a natural water amenity in their listing title (excluding lakes), we find a similarly weak positive relationship between restoration and property counts but a 53 percent increase in revenue per property. The coefficient on treatment systems, in contrast, is near zero.

Although the point estimate on the impaired and restored indicators have wide confidence intervals, they are consistent with findings for the resident population. The college-educated and short-term visitors have considerable choice over where they live and visit. Finding that they avoid places with impaired waterways and favor those

[1] The effects are estimated using a Poisson model, and the percent change is calculated as a transformation of the coefficients on impairment in Table S7, for example $62 = 100 \cdot (exp(-.958) - 1)$.

with some restoration points to waterway quality contributing to the overall appeal and quality of life of a place.

By comparison, the presence of a multi-use trail is always associated with substantially more rentals and revenue per rental. This may reflect the extensive nature of many of the trails, which run for long distances and attract bikers on multi-day trips. In contrast, restored waterways are scattered across the landscape and can vary in size, some too small to kayak. Restoration of these may be appreciated by residents but not attract over-night visitors.

3 Methods

Our empirical analysis exploits the extensive network of mine-impaired and restored waterways that extend across the large swaths of Pennsylvania that have historically produced coal.

3.1 Empirical Approach

Our empirical approach compares population growth across census tracts within the same county that differ in their waterway conditions. We ask whether tracts with mine-impaired waterways grew less (or shrank more) than similar tracts with clean waterways, and whether restoration reversed this penalty. For our core model, we regress the change in the natural log of a census tract's population (from 1990 to 2020) on variables indicating the presence of any waterway (W), the presence of a mine-impaired waterway (I), the presence of a waterway restored during the study period (R), and a county fixed effect ($\alpha_{c(i)}$) that accounts for shocks (e.g., industrial decline) occurring in tract i's part of the state.

$$\Delta \ln(Pop_{i,1990-2020}) = \alpha_{c(i)} + \beta_1 W_i + \beta_2 I_{i,1990} + \beta_3 R_{i,1990-2020} + \varepsilon_i \quad (1)$$

The indicator variables are nested, with all impaired tracts having waterways and all restored tracts having some impaired waterways as of 1990. The nesting permits estimating the effect of having any waterway (β_1), having at least one mine-impaired waterway (β_2), and having restoration of at least one of the mine-impaired waterways (β_3). The waterway indicator is not of direct interest but accounts for any systematic differences between places with waterways (e.g. lower lying areas) and those without them.

The coefficient β_2 measures the difference in population growth between tracts with impaired waterways and tracts with no mine-impaired waterways, within the same county. Because the dependent variable is the difference in the natural log of population, the coefficient β_2 gives difference in population growth rates, measured in percentage points, between tracts where the indicator equals one and similar tracts where it equals zero. As a rule, impairment occurred before 1990, driven by mining practices common before states adopted modern regulations following the federal Surface Mining Control and Reclamation Act of 1977. Thus, the impairment indicator measures how population changed in already-impaired places separate from any broader economic trends affecting the county as a whole. In our most robust specification, we also control for initial coal mining employment per capita in the tract. This

separates the effect of impairment on population decline from the effect of preexisting economic dependence on mining.

Unlike the impairment indicator, the restoration indicator is based on changes in waterway status that occurred over the 1990-2020 period because almost all treatment systems were built after 1990. It indicates that at least one waterway segment would be impaired by acidity or high concentrations of aluminum, iron, or manganese if not for systems that treat upstream mine discharges [21]. Because restoration can only occur in places with impairment, β_3 measures how population growth differed in impaired tracts with some restoration relative to impaired tracts without restoration. In our most robust specification, we control for the number of treatment systems in the tract, so our measured growth differentials are apart from any effects of direct spending on constructing and maintaining treatment systems.

In two specifications, we add to the indicator variables their continuous counterparts: miles of any waterway, miles of impaired waterways, and miles of restored waterways, all normalized by the tract's area. Including both indicator and continuous variables permits estimating the discrete effect of impairment or restoration, such as from stigma effects, and an intensive margin effect.

In addition to controlling for initial tract-level mining employment and the count of treatment systems, our most rigorous specification adds baseline (1990) tract-level variables related to household income, education, employment, and rurality. These account for time-varying, within-county factors affecting tracts differently based on initial characteristics, such as their rurality. For rurality, we control for a tract's land area; because tracts are drawn to have roughly similar populations, the larger the tract, the more rural it is. Using this rigorous model we also estimate population effects by age and education.

3.1.1 Short-Term Rental Activity

We analyze short-term rental activity using the same independent variables as in our population analysis. But because rental activity is skewed across tracts and some have zero activity, we estimate a Poisson model, which relates expected rental activity using an exponential function ($E[STR|X] = exp(X\beta)$) that can handle zeros while also giving coefficients that can be interpreted as percent differences. Taking the natural log of short-term rental activity would require adopting a fix for zero values, which can be arbitrary and yet have considerable influence on estimates [24].

We observe rental activity only in recent years (2015-2024), after most restoration occurred. Short-term rentals were less common in 1990, before restoration, so many of the rentals would have commenced operation afterwards. However, rental outcomes do not represent a true change over time. The proper interpretation of the coefficients on the restored indicator, for example, is how much more rental activity restored places have (post-restoration) compared to places with impairment, no restoration, and similar baseline (1990) conditions. For a large coefficient, the exact percent effect equals $100(exp(\beta_{restored}) - 1)$.

3.1.2 Causality and Interpretation

In our most robust model (Table 1, column 4), we interpret the coefficient on impairment as the enduring causal effect of legacy pollution and the coefficient on restoration as the effect of undoing some of it. Mine-impaired waterways are scattered throughout large swaths of the state, highlighting how impairment was not an isolated event affecting unique places (see Figures 1a and 1b). Rather, they reflect historical market and policy forces largely outside the influence of local actors. They also reflect a mix of unique subsurface geology and topography. This is made clear in more than 70 "Operation Scarlift" reports of mine-related waterway problems funded by the state of Pennsylvania that describe diverse geological conditions that amplify or attenuate the drainage effects from abandoned mines, such as the presence of alkaline material [25].

Although impairment existed before 1990 in most places, its prior effects are reflected in part by our 1990 socioeconomic control variables. Moreover, regional economic shocks are accounted for by county fixed effects. The coefficient on impairment, therefore, captures how legacy pollution affected population change from 1990 to 2020, beyond any effects already reflected in 1990 baseline conditions or absorbed by county-level trends.

Unlike impairment, restoration is arguably not randomly distributed. It occurs after 1990 and depends in part on local initiative, raising concerns about selection bias. Although funded primarily by state and federal money, many treatment systems are built and maintained through partnerships between the Pennsylvania Department of Environmental Protection and local watershed groups [26]. According to qualitative research, the presence and success of these groups depend in part on social capital and the presence of skilled and committed local leaders [27]. As such, social capital may be an omitted variable positively correlated with restoration and population growth. We address this possibility in two ways. First, our main specification controls for the presence of treatment systems in the tract, which absorbs social capital differences correlated with where systems are built. This is possible because many tracts in our sample benefit from upstream restoration without having local systems, providing variation in restoration status apart from restoration work. Second, in a robustness check we control for three measures of social capital produced from social media data: economic connectedness, the volunteering rate, and the density of civic organizations [23]. Although including the variables risks overcontrolling since increased social capital could stem from restoration efforts, it is the most direct way for testing whether our results might be confounded by social capital differences.

3.2 Sample and Data

Our sample includes 1,756 census tracts across Pennsylvania counties that had mine-impaired waterways as of 1990. This covers roughly half the state and excludes the Southeastern region, which has distinct economic characteristics and growth trends. The core population and demographic data for our analysis come from the U.S. Census Bureau and GeoLytics, which provides boundary-constant measures across decennial censuses (using 2020 boundaries).

We classify segments as restored if they would be impaired by mine drainage but for treatment systems built after 1990. To identify this counterfactual impairment status, we follow the methodology of prior research with updated data from Datashed to produce measures of waterway segment-level restoration based on model simulations \cite{black2024treating} and cross-checked with the listing of mine-impaired segments by the PA Department of Environmental Protection. Datashed is a public repository of information on mine drainage treatment systems in Pennsylvania (see SI for details). In addition to providing the location of treatment systems, which allows us to construct tract-level system indicators, Datashed includes water quality measurements at system inflow and outflow points that permit estimation of downstream impairment absent the systems.

We classify segments as impaired in 1990 if they were subsequently restored by post-1990 treatment systems, or remain impaired according to Pennsylvania's 2022 Integrated Water Quality Report. Since most improper mine abandonment occurred before 1990 and untreated impairment persists, this approach provides a reasonable approximation of 1990 impairment status.

We provide data sources and measurement details for coal employment, treatment system counts, bike trails, social capital, and short-term rentals in the Supplementary Information.

4 Discussion and Conclusion

4.1 Restored Amenities as Economic Development Policy

Restoring mine-impaired waterways can have population effects on par with traditional economic development incentives and may be more cost-effective. The effect is comparable to that of Empowerment Zones (6 p.p.), which represents a traditional economic development program consisting primrily in business incentives, in this case federal tax breaks and grants targeting qualified areas [28]. Empowerment Zones had a larger effect on employment, which is based on where people work, not work they live. The much smaller effect on population highlights how tax incentives can increase commuting into a community without making it a more attractive place to live.

Regarding cost-effectiveness at attracting people, Empowerment Zone wage credits and grants cost around $1,500 (in 2024 dollars) per resident of an Empowerment Zone (tract) [28]. By comparison, the cost of 25 years of restoration is about $240 per resident of tracts with restored waterways [21].[2]

The effect of restoration on population growth stems from the amenity it creates, not the spending on construction and operation of treatment systems, which is often highlighted as the primary channel of economic impact [29, 30]. Three lines of reasoning support the conclusion. First, construction spending and employment is likely spread across various contractors throughout the county or region, and our estimates are based on within-county comparisons. Second, tracts with treatment systems show no additional population gains when controlling for restoration status. Third, the largest

[2] Total treatment cost is calculated as $5,720 per km per year · 1,500 km · 25 years, based on [21]. Dividing by the total initial population of restored tracts (3,657 · 237 as shown in Table S1) gives a cost of $242 per resident.

population effect in percent terms is for seniors, who are more likely attracted by amenities than employment opportunities.

4.2 The Downstream Effects of Attracting the Educated and Seniors

The demographic shifts brought by restoration can help stabilize local economies. More educated populations tend to place a high value on natural amenities [31]. Unsurprisingly, our results show impairment repelling them and restoration attracting them. By increasing the presence of educated residents, restoration creates an additional channel for influencing community economic prospects. Estimates of the effect of education on subsequent employment growth suggest that growth of the college-educated population share, by itself, would increase employment growth by 0.5 percentage points [32].[3]

The increased employment growth among more educated populations has several sources. One is the productivity-enhancing effect of education on the worker herself and her co-workers. A greater presence of college graduates, for example, leads to greater wages among the non-college educated [33]. Another channel is that the educated tend to support more local amenities like restaurants and local public goods through greater volunteering [32, 34]. Third, educated populations help communities adapt to economic shocks. Rust-belt cities with more college graduates were better able to transition away from declining manufacturing in the late 20th century [35]—directly relevant given our study region's 32 percent decline in goods-producing employment over the period.

Attracting retirees further stimulates local economies. Seniors who have retired are mobile and often move from high-cost urban areas to lower-cost rural areas with amenities. Their greater spending provides demand for local businesses: one study found a 1 percent population increase from senior migration led to 2.75 percent greater employment [36]. If senior migration had a similar effect in our context and half of the growth in the senior population was from migration, it would imply about 2 percent greater employment in restored communities.[4]

4.3 Policy Priorities

Our findings suggest that restoring natural amenities deserves recognition as a viable economic development strategy in some contexts. Restoration will not recreate the economy or demographics of prior eras, but it makes communities better places to live, which helps them attract or retain residents, especially educated ones important for well-functioning firms, schools, and governments.

[3] For restored tracts, the larger increase in the college-educated population than the general population results in a 7 percent increase in the college-educated share of the population (from 7.5 percent to 8.0 percent). Based on the estimate in [32], which gave an 0.8 percent employment effect for a 10 percent increase in the college share, this translates into 0.6 percentage points greater employment growth ($= 0.7 \cdot 0.8$).

[4] $\approx 0.5\cdot$ senior-driven population growth (1.76) $\cdot$ employment effect (2.75), where senior-driven population growth comes from multiplying the initial senior-share of the population (.16) by the restoration-driven growth in the senior population (11 percentage points greater growth).

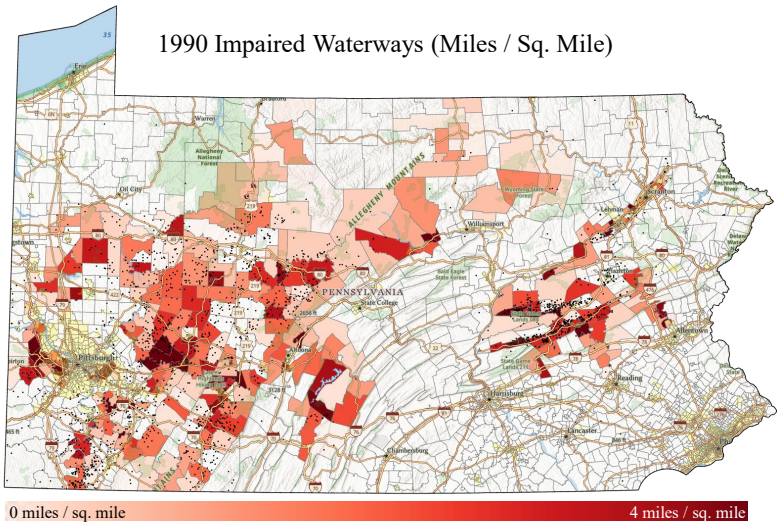
State and local economic development groups should consider within their purview efforts to develop or restore natural amenities. Completing mine drainage treatment systems often requires overcoming significant costs of coordinating among landowners, watershed groups, and public agencies. Development staff can serve as 'fixers' to overcome coordination costs. They can also help watershed groups navigate grant applications and secure financing to bridge the gap between project expenditures and reimbursements from government agencies. This can prevent restoration efforts from stalling or dying. Applying for and managing grants for mine drainage treatment can involve years of navigating a labyrinth of funding sources and requirements, which can exhaust the resources and patience of watershed groups dependent on volunteers [27].

Public funds for mine drainage treatment can also go further if watershed groups spend less time mired in slow or dead-end bureaucratic processes. For example, an audit of the federal Abandoned Mine Land Economic Revitalization Program found that the office administering it had no clear timeline for completing reviews and at least one application languished for over 1,100 days before being withdrawn [37]. If public agencies reduce application and reporting burdens and shorten review times, it economizes the valuable time and interest of grassroots groups that help restoration projects succeed.

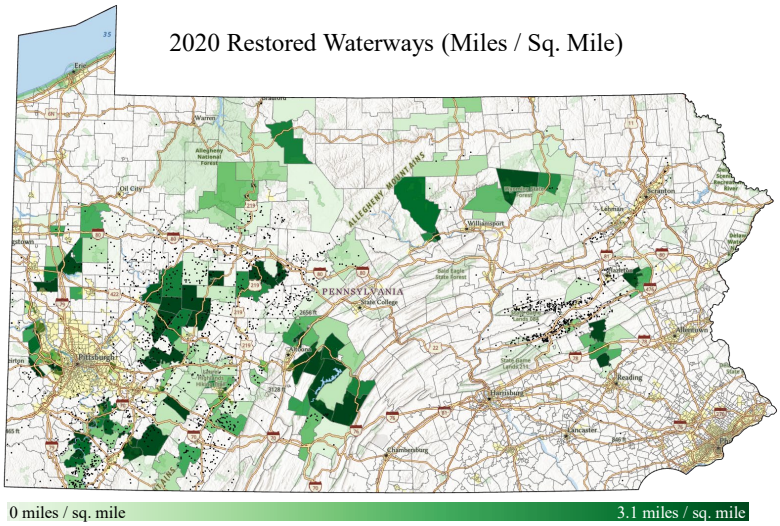
Lastly, our findings of broad benefits from restoration underscore the value of funding for restoration projects. U.S. House Bill 6938 would divert some Infrastructure Investment and Jobs Act funding from abandoned mine remediation to other uses. Yet existing appropriations already fall short of addressing Pennsylvania's known hazards [21], meaning that such diversions will leave more waterways impaired and the surrounding communities without the economic benefits restoration provides. The same is likely true in other Appalachian coal states. Policy makers considering cuts should see investments in environmental restoration as helping to stabilize and even revitalize post-industrial communities struggling to attract and retain residents.

5 Figures

a



b



c

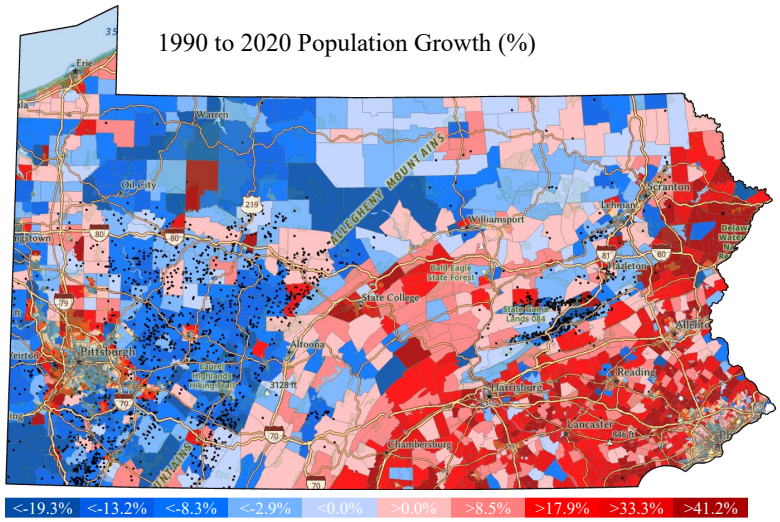


Fig. 1 **a**, Waterways impaired by mine drainage as of 1990 **b**, Waterways restored from mine drainage over 1990-2020 **c**, Population change, 1990-2020

Fig. 2 Miller's Run (Allegheny County) before and after construction of AMD treatment system. *Note:* The pictures were taken two weeks apart. Photo credit: South Fayette Conservation Group.

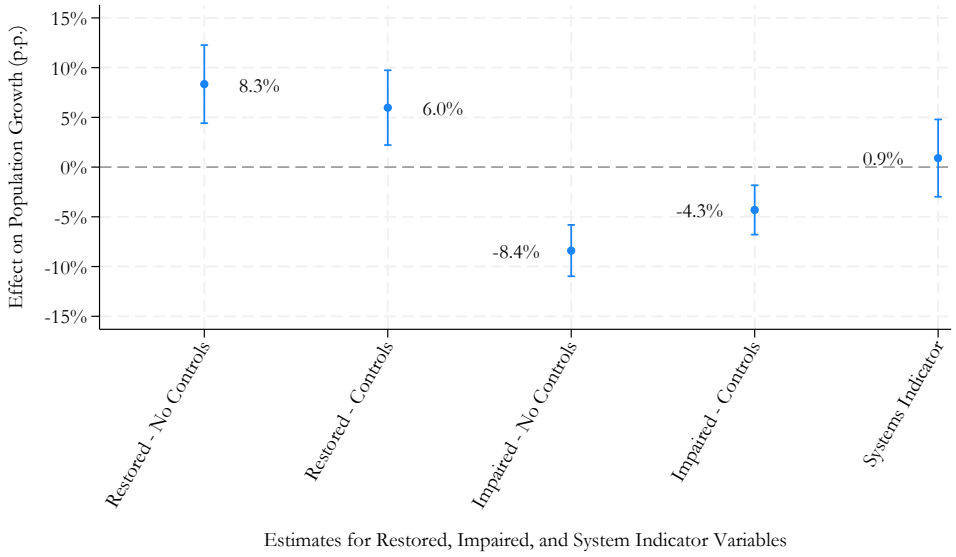


Fig. 3 Main Coefficient Estimates for Impaired and Restoration Indicator Variables
Note: The bars show 90 percent confidence intervals based on robust standard errors. The No Controls estimates correspond to column 1 of Table 1. The Controls estimates correspond to column 4 of Table 1.

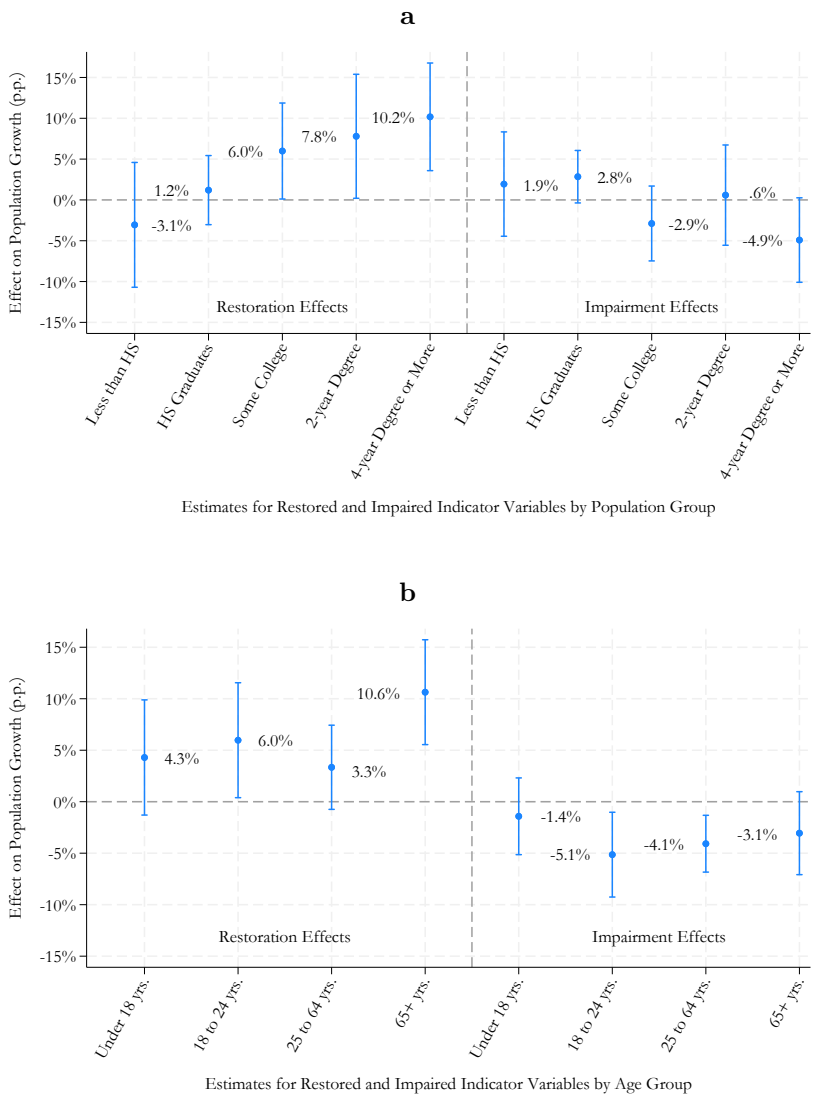


Fig. 4 Population growth effects by education (**a**) and age group (**b**)

Note: Restored and impaired coefficient estimates for the same population group (e.g. Under 17 yrs) are from the same regression. The left and right panels of each figure show estimates from four regressions, one for each outcome. Error bars represent 90 percent confidence intervals based on robust standard errors. All estimates are based on the most rigorous specification, which includes the same controls and sample as column 4 of Table 1.

6 Tables

Table 1. Estimated Effects of Impairment and Restoration on Population Growth.

Variables	(1) ln(2020 pop) - ln(1990 pop)	(2) ln(2020 pop) - ln(1990 pop)	(3) ln(2020 pop) - ln(1990 pop)	(4) ln(2020 pop) - ln(1990 pop)
I(Restored Streams)	0.083***	0.064**	0.052**	0.060***
	(0.024)	(0.027)	(0.025)	(0.023)
Miles of Restored Streams / Sq. Mile		0.029	0.013	
		(0.058)	(0.054)	
I(Impaired Streams)	-0.084***	-0.049**	-0.027	-0.043***
	(0.016)	(0.019)	(0.019)	(0.015)
Miles of Impaired Streams / Sq. Mile		-0.048***	-0.022	
		(0.015)	(0.014)	
I(Streams)	0.107***	0.101***	0.000	0.012
	(0.025)	(0.033)	(0.032)	(0.024)
Miles of Streams / Sq. Mile		0.005	0.008	
		(0.012)	(0.011)	
I(Treatment Systems)			0.009	0.009
			(0.024)	(0.024)
Std. 1990 Household Income			0.079***	0.079***
			(0.021)	(0.021)
Std. 1990 Percent of Persons 25+ w/High-School Education or More			0.017	0.017
			(0.018)	(0.018)
Std. 1990 Percent of Persons 16+ Unemployed			-0.075***	-0.076***
			(0.011)	(0.011)
Std. 1990 Mining Employment per Capita			0.000	0.000
			(0.004)	(0.004)
Std. Tract Area			-0.009*	-0.008
			(0.005)	(0.005)
Constant	-0.067***	-0.069***	0.037	0.039
	(0.023)	(0.023)	(0.024)	(0.024)
Observations	1,756	1,756	1,756	1,756
R-squared	0.238	0.241	0.352	0.352

Note: Robust standard errors in parentheses. All regressions include county fixed effects. Control variable with "Std." have been standardized with a mean zero and a standard deviation of one.

Supplementary Information

Additional Data Sources and Details

We calculate 1990 coal mine employment at the tract level using data from the federal Mine Safety and Health Administration (MSHA). MSHA reports employment at the mine level, which we assign to a tract and then sum by tract. Bike trail data come from the Pennsylvania Department of Conservation and Natural Resources "Explore PA Trails" data, available through the website of Pennsylvania Spatial Data Access. Treatment system counts come from Datashed.

The methodology for identifying a waterway segment as restored is based on system treatment effects (weighted by flow) on acidity, iron, aluminum, and manganese of all known post-1990 systems upstream of the segment in question. If, apart from all upstream systems, a segment would be impaired on account of any of these indicators, it is identified as restored. Miles of impaired waterways depends heavily on data tabulated from the Pennsylvania Department of Environmental Quality 2022 Integrated Water Quality Report. The Report identifies all waterway segments impaired by mine drainage through a 30-year assessment cycle, or more frequently if significant remediation occurs nearby (see [21], Supplementary Note 4).

We construct three tract-level social capital variables from ZIP Code variables released as part of the Social Capital Atlas [23]. The variables are based on Facebook users aged 25 to 44 residing in the United States, were active on Facebook in the last 30 days (at the time of collection), had at least 100 U.S.-based Facebook friends, and have a residential ZIP code.[5] The economic connectedness variable is based on identifying individuals as having a high or low socioeconomic status and then calculating the average share of high-SES friends among low-SES individuals of a place. The second variable, the volunteer rate, is the percentage of Facebook users of a place who are members of group related to volunteering or activism. The third variable is the density of civic organizations, estimated as the number of Facebook pages related to public goods–as indicated by page characteristics–per 1,000 users in the place.

Not all ZIP codes had sufficient Facebook data for calculating the measures. If a tract did not overlap with any ZIP code with data, it was coded as missing data. Otherwise, a tract's social capital variable was based on an area-weighted average of the values of all ZIP codes that overlap it. In total, we could construct social capital variables for 73 percent of our sample tracts.

We obtained proprietary data on short-term rentals from AirDNA, which primarily reflects data scraped from the main short-term rental listing platforms, Airbnb and VRBO. The raw data for Pennsylvania include 4.7 million property-by-month records. Collapsing by year and census tract, we calculate the number of unique rentals listed at some point in the year as well as the estimated revenue they generated. AirDNA infers booked nights from listing calendar availability and estimates revenue by combining inferred occupancy with observed or imputed nightly prices. As a result, reported revenue reflects model-based estimates rather than realized bookings.

[5] See the README file for Social Capital Data by ZIP Code at https://opportunityinsights.org/data/.

Supplementary Figures

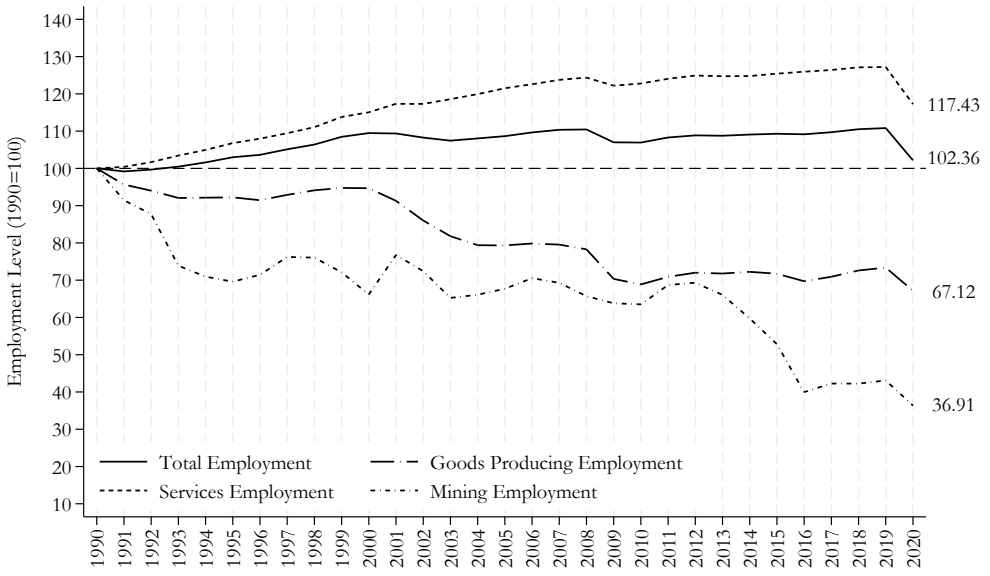


Fig. S1 Employment trends in Pennsylvania counties with some coal employment as of 1990
Note: Source: Quarterly Census of Employment and Wages, Bureau of Labor Statistics. By construction, goods producing employment excludes mining.

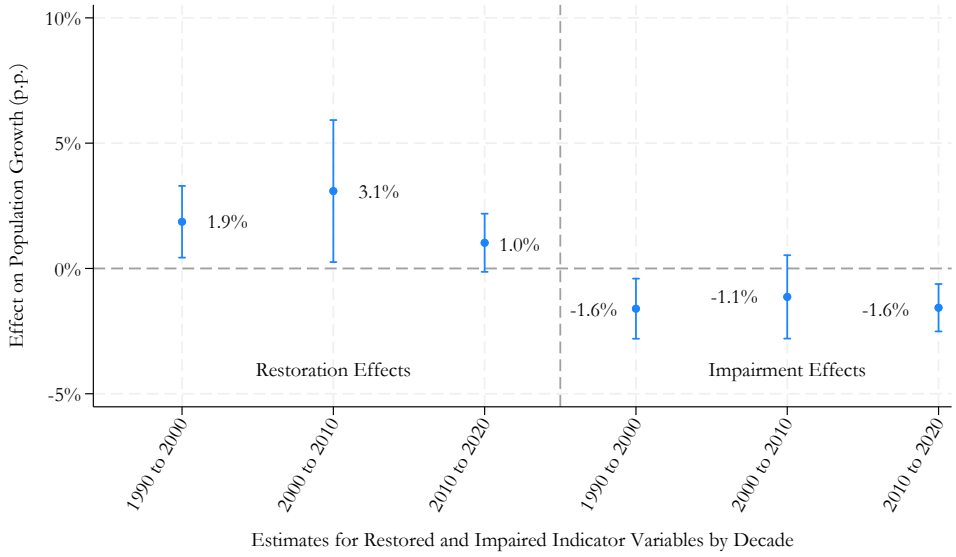


Fig. S2 Coefficient Estimates for Impaired and Restoration Indicator, By Decade
Note: The bars show 90 percent confidence intervals based on robust standard errors. The estimates are based on three regressions, one for each decade. All estimates are based on the most rigorous specification, which includes the same controls and sample as column 4 of Table 1.

Supplementary Tables

Table S1. Sample Mean Values by Tract Group.

Variable / Sample Averages	All Census Tracts in Counties with Impairment	Tracts Without Streams in Counties With Impairment	Tracts With Unimpaired Streams in Counties With Impairment	Tracts With Impaired but Unrestored Streams	Tracts With Impaired but Some Restored Streams
1990 to 2020 Population Growth	1.4%	-5.1%	6.6%	-8.7%	-3.5%
1990 Population	3,476	3,012	3,431	3,736	3,743
2020 Population	3,566	2,921	3,691	3,486	3,657
2020 Population Working from Home	106	94	118	88	87
Number of Short-Term Rental Properties (All Properties)	8.59	13.55	8.80	4.63	8.35
Average Revenue per Short-Term Rental Property (All Properties)	5,385	4,751	5,294	4,995	6,779
Number of Short-Term Rental Properties (Water-Amenity Properties)	0.42	0.09	0.35	0.40	1.01
Average Revenue per Short-Term Rental Property (Water-Amenity Properties)	1,883	442	1,677	1,800	4,078
1990 Population (Under 18 yrs.)	794	623	788	840	908
1990 Population (18 to 24 yrs.)	341	419	325	354	333
1990 Population (25 to 64 yrs.)	1,758	1,442	1,759	1,852	1,907
1990 Population (65+ yrs.)	582	527	559	689	595
1990 Population (Less than HS)	128	102	134	130	121
1990 Population (HS Graduates)	963	700	934	1,096	1,147
1990 Population (Some College)	288	260	299	290	264
1990 Population (2-year Degree)	596	530	555	708	688
1990 Population (4-year Degree or More)	365	376	396	317	281
I(Restored Streams)	13%	0%	0%	0%	100%
Miles of Restored Streams / Sq. Mile	0.0	0.0	0.0	0.0	0.3
I(Impaired Streams)	30%	0%	0%	100%	100%
Miles of Impaired Streams / Sq. Mile	0.19	0.00	0.00	0.74	0.50
I(Streams)	89%	0%	100%	100%	100%
Miles of Streams / Sq. Mile	1.60	0.00	1.77	1.74	2.03
I(Treatment Systems)	7%	0%	0%	20%	27%
Number of Treatment Systems	0.19	0.00	0.01	0.42	0.87
I(Bike Trails)	38%	5%	37%	45%	57%
1990 Household Income	67,127	60,532	72,075	60,156	59,490
1990 Percent of Persons 25+ w/High-School Education or More	74%	74%	76%	72%	72%
1990 Percent of Persons 16+ Unemployed	7%	9%	6%	7%	8%
1990 Mining Employment per Capita	0.00	0.00	0.00	0.00	0.00
Number of Tracts	1,756	197	1,034	288	237

Note: The sample includes all tracts in all counties that had at least some mine-impaired waterways as of 1990.

Table S2. Population Growth Effects By Decade.

Variables	(1) ln(2000 pop) - ln(1990 pop)	(2) ln(2010 pop) - ln(2000 pop)	(3) ln(2020 pop) - ln(2010 pop)	(4) ln(2020 pop) - ln(1990 pop)
I(Restored Streams)	0.019**	0.031*	0.010	0.060***
	(0.009)	(0.017)	(0.007)	(0.023)
I(Impaired Streams)	-0.016**	-0.011	-0.016***	-0.043***
	(0.007)	(0.010)	(0.006)	(0.015)
I(Streams)	0.040***	-0.037*	0.009	0.012
	(0.012)	(0.021)	(0.008)	(0.024)
I(Treatment Systems)	0.007	-0.000	0.002	0.009
	(0.010)	(0.020)	(0.007)	(0.024)
Std. 1990 Household Income	0.032***	0.030***	0.018***	0.079***
	(0.008)	(0.010)	(0.006)	(0.021)
Std. 1990 Percent of Persons 25+ w/High-School Education or More	0.019**	0.002	-0.005	0.017
	(0.008)	(0.012)	(0.006)	(0.018)
Std. 1990 Percent of Persons 16+ Unemployed	-0.019**	-0.035***	-0.022***	-0.076***
	(0.009)	(0.011)	(0.006)	(0.011)
Std. 1990 Mining Employment per Capita	0.001	0.001	-0.001	0.000
	(0.001)	(0.004)	(0.001)	(0.004)
Std. Tract Area	0.008***	-0.009**	-0.006***	-0.008
	(0.002)	(0.004)	(0.002)	(0.005)
Constant	-0.014	0.054***	-0.001	0.039
	(0.011)	(0.020)	(0.007)	(0.024)
Observations	1,756	1,756	1,756	1,756
R-squared	0.303	0.170	0.262	0.352

Note: Robust standard errors in parentheses. All regressions include county fixed effects. The control variables are the same (held at 1990 levels) for all regressions.

Table S3. Population Growth Effects By Education.

	(1)	(2)	(3)	(4)	(5)
Population Sample	Persons 25+ Less Than High School	Persons 25+ With High School Degree	Persons 25+ With Some College	Persons 25+ With 2-year Degree	Persons 25+ with 4-year Degree or More
Variables	ln(2020 pop) - ln(1990 pop)	ln(2020 pop) - ln(1990 pop)	ln(2020 pop) - ln(1990 pop)	ln(2020 pop) - ln(1990 pop)	ln(2020 pop) - ln(1990 pop)
I(Restored Streams)	-0.031	0.012	0.060*	0.078*	0.102**
	(0.046)	(0.026)	(0.036)	(0.046)	(0.040)
I(Impaired Streams)	0.019	0.028	-0.029	0.006	-0.049
	(0.039)	(0.019)	(0.028)	(0.037)	(0.031)
I(Streams)	-0.089	0.080**	0.159***	0.132**	0.210***
	(0.066)	(0.032)	(0.039)	(0.056)	(0.051)
I(Treatment Systems)	-0.002	0.003	0.038	0.104**	0.017
	(0.044)	(0.027)	(0.040)	(0.046)	(0.044)
Std. 1990 Household Income	0.063*	0.072***	-0.005	-0.038	0.068**
	(0.035)	(0.023)	(0.024)	(0.027)	(0.033)
Std. 1990 Percent of Persons 25+ w/High-School Education or More	0.061*	-0.101***	-0.195***	-0.115***	-0.167***
	(0.032)	(0.019)	(0.025)	(0.029)	(0.033)
Std. 1990 Percent of Persons 16+ Unemployed	0.013	-0.065***	-0.061***	-0.077***	-0.092***
	(0.023)	(0.015)	(0.017)	(0.026)	(0.029)
Std. 1990 Mining Employment per Capita	0.008	0.011	0.004	-0.003	0.004
	(0.009)	(0.006)	(0.007)	(0.011)	(0.006)
Std. Tract Area	0.003	0.014**	0.031***	0.042***	0.064***
	(0.011)	(0.006)	(0.009)	(0.012)	(0.012)
Constant	-1.102***	-0.149***	0.181***	0.488***	0.515***
	(0.063)	(0.031)	(0.038)	(0.054)	(0.049)
Observations	1,740	1,755	1,754	1,751	1,755
R-squared	0.237	0.354	0.301	0.163	0.137

Note: Robust standard errors in parentheses. All regressions include county fixed effects.

Table S4. Population Growth Effects By Age Group.

	(1)	(2)	(3)	(4)	(5)
Population Sample	All Ages	Under 18 Years	18 to 24 Years	25 to 64 Years	65+ years
Variables	ln(2020 pop) - ln(1990 pop)	ln(2020 pop) - ln(1990 pop)	ln(2020 pop) - ln(1990 pop)	ln(2020 pop) - ln(1990 pop)	ln(2020 pop) - ln(1990 pop)
I(Restored Streams)	0.060***	0.043	0.060*	0.033	0.106***
	(0.023)	(0.034)	(0.034)	(0.025)	(0.031)
I(Impaired Streams)	-0.043***	-0.014	-0.051**	-0.041**	-0.031
	(0.015)	(0.023)	(0.025)	(0.017)	(0.024)
I(Streams)	0.012	-0.004	-0.019	-0.000	0.195***
	(0.024)	(0.034)	(0.038)	(0.026)	(0.035)
I(Treatment Systems)	0.009	0.014	-0.001	0.003	-0.009
	(0.024)	(0.029)	(0.039)	(0.027)	(0.034)
Std. 1990 Household Income	0.079***	0.047**	0.124***	0.035*	0.227***
	(0.021)	(0.018)	(0.026)	(0.019)	(0.046)
Std. 1990 Percent of Persons 25+ w/High-School Education or More	0.017	0.039	0.010	-0.021	0.152***
	(0.018)	(0.024)	(0.025)	(0.019)	(0.029)
Std. 1990 Percent of Persons 16+ Unemployed	-0.076***	-0.062***	-0.056***	-0.078***	-0.047**
	(0.011)	(0.016)	(0.019)	(0.011)	(0.020)
Std. 1990 Mining Employment per Capita	0.000	-0.009**	-0.000	-0.001	0.004
	(0.004)	(0.004)	(0.006)	(0.005)	(0.005)
Std. Tract Area	-0.008	-0.050***	-0.033***	-0.024***	0.105***
	(0.005)	(0.009)	(0.008)	(0.005)	(0.013)
Constant	0.039	-0.253***	-0.035	0.052**	0.219***
	(0.024)	(0.032)	(0.036)	(0.025)	(0.037)
Observations	1,756	1,756	1,756	1,756	1,756
R-squared	0.352	0.282	0.245	0.243	0.510

Note: Robust standard errors in parentheses. All regressions include county fixed effects.

Table S5. Population Growth Effects When Adding Multi-Use Trail Indicator Variable.

Variables	(1) ln(2020 pop) - ln(1990 pop)	(2) ln(2020 pop) - ln(1990 pop)	(3) ln(2020 pop) - ln(1990 pop)	(4) ln(2020 pop) - ln(1990 pop)
I(Restored Streams)	0.078**	0.060**	0.061**	0.068**
	(0.032)	(0.030)	(0.027)	(0.029)
Miles of Restored Streams / Sq. Mile		0.026	0.008	
		(0.059)	(0.055)	
I(Impaired Streams)	-0.087***	-0.054***	-0.034*	-0.047***
	(0.016)	(0.020)	(0.019)	(0.015)
Miles of Imapired Streams / Sq. Mile		-0.045***	-0.018	
		(0.015)	(0.014)	
I(Streams)	0.099***	0.097***	-0.005	0.001
	(0.025)	(0.033)	(0.032)	(0.024)
Miles of Streams / Sq. Mile		0.003	0.005	
		(0.012)	(0.011)	
I(Treatment Systems)			0.009	0.009
			(0.023)	(0.023)
I(Bike Trails)	0.031*	0.028	0.041**	0.043***
	(0.017)	(0.018)	(0.017)	(0.016)
I(Bike Trails) x I(Restoration)	0.005	0.006	-0.017	-0.019
	(0.039)	(0.038)	(0.036)	(0.036)
Std. 1990 Household Income			0.079***	0.080***
			(0.021)	(0.021)
Std. 1990 Percent of Persons 25+ w/High-School Education or More			0.018	0.018
			(0.018)	(0.017)
Std. 1990 Percent of Persons 16+ Unemployed			-0.074***	-0.075***
			(0.011)	(0.011)
Std. 1990 Mining Employment per Capita			-0.000	-0.000
			(0.004)	(0.004)
Std. Tract Area			-0.010**	-0.009*
			(0.005)	(0.005)
Constant	-0.070***	-0.072***	0.033	0.035
	(0.023)	(0.023)	(0.024)	(0.024)
Observations	1,756	1,756	1,756	1,756
R-squared	0.240	0.242	0.355	0.355

Note: Robust standard errors in parentheses. All regressions include county fixed effects.

Table S6. Population Growth Effects When Adding Social Capital Variables.

Variables	(1) ln(2020 pop) - ln(1990 pop)	(2) ln(2020 pop) - ln(1990 pop)	(3) ln(2020 pop) - ln(1990 pop)	(4) ln(2020 pop) - ln(1990 pop)
I(Restored Streams)	0.031*	0.032*	0.032*	0.031*
	(0.019)	(0.019)	(0.019)	(0.019)
I(Impaired Streams)	-0.027*	-0.027*	-0.026*	-0.026*
	(0.014)	(0.014)	(0.014)	(0.014)
I(Streams)	-0.007	-0.014	-0.015	-0.014
	(0.024)	(0.024)	(0.023)	(0.024)
I(Treatment Systems)	-0.000	-0.003	-0.003	-0.002
	(0.019)	(0.019)	(0.019)	(0.019)
Std. 1990 Household Income	0.047***	0.042***	0.042***	0.041***
	(0.014)	(0.013)	(0.013)	(0.013)
Std. 1990 Percent of Persons 25+	0.006	0.000	0.001	0.001
w/High-School Education or More	(0.017)	(0.017)	(0.017)	(0.017)
Std. 1990 Percent of Persons 16+	-0.061***	-0.056***	-0.056***	-0.059***
Unemployed	(0.010)	(0.010)	(0.010)	(0.010)
Std. 1990 Mining Employment per Capita	0.003	0.005	0.005	0.005
	(0.004)	(0.004)	(0.004)	(0.004)
Std. Tract Area	0.008	0.013**	0.014**	0.014**
	(0.005)	(0.006)	(0.006)	(0.006)
Economic connectedness		0.131***	0.137***	0.137***
		(0.037)	(0.039)	(0.039)
Volunteering rate			-0.219	-0.250
			(0.379)	(0.380)
Civic organizations rate				0.356
				(0.422)
Constant	-0.005	-0.111***	-0.101***	-0.105***
	(0.023)	(0.037)	(0.037)	(0.038)
Observations	1,281	1,281	1,281	1,281
R-squared	0.308	0.318	0.319	0.319

Note: Robust standard errors in parentheses. All regressions include county fixed effects.

Table S7. Impairment and Restoration Effects on Short-Term Rental Counts and Revenue per Property.

Sample	(1) *All Properties*	(2) *All Properties*	(3) *Water-Amenity Properties*	(4) *Water-Amenity Properties*
Variables	Property Count	Revenue per Property	Property Count	Revenue per Property
I(Restored Streams)	0.183	0.053	0.191	0.426*
	(0.181)	(0.092)	(0.265)	(0.229)
I(Impaired Streams)	-0.958***	-0.054	-0.076	-0.259
	(0.205)	(0.072)	(0.215)	(0.234)
I(Streams)	-0.598***	-0.093	0.662	0.576
	(0.118)	(0.063)	(0.538)	(0.455)
I(Treatment Systems)	0.304	0.098	-0.112	-0.019
	(0.192)	(0.100)	(0.280)	(0.223)
Std. 1990 Household Income	0.001	0.066*	0.001	0.220**
	(0.058)	(0.038)	(0.185)	(0.102)
Std. 1990 Percent of Persons 25+ w/High-School Education or More	0.038	0.020	0.086	-0.172
	(0.093)	(0.045)	(0.161)	(0.138)
Std. 1990 Percent of Persons 16+ Unemployed	0.067	-0.064*	0.169	-0.068
	(0.053)	(0.038)	(0.112)	(0.131)
Std. 1990 Mining Employment per Capita	-0.104*	0.003	-0.123	-0.010
	(0.055)	(0.019)	(0.103)	(0.043)
Std. Tract Area	0.266***	0.200***	0.474***	0.313***
	(0.069)	(0.022)	(0.055)	(0.052)
I(Bike Trails)	0.710***	0.152***	0.989***	0.781***
	(0.143)	(0.053)	(0.189)	(0.164)
Constant	1.179***	6.713***	-4.408***	3.070***
	(0.133)	(0.095)	(0.525)	(0.481)
Observations	17,560	17,560	17,560	17,560

Note: Robust standard errors clustered by tract in parentheses. All regressions include county fixed effects.

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