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Wetland Loss in Coastal Louisiana Drives Significant Resident Population Declines

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Abstract: Despite increased hurricane intensity, the U.S. Gulf of Mexico coast has experienced dramatic coastal population increase of 24.5% from 2000 to 2016. However, in coastal Louisiana areas with dramatic wetland loss, parishes have experienced population declines and lower rates of population growth. Therefore, understanding the magnitude of the effect of wetland loss as a main driver in population loss in coastal Louisiana is critical. Using regression analysis, this study finds that wetland loss has a significant and persistent negative effect on population growth in coastal Louisiana. This effect resulted in a reduction in the population growth rate in coastal parishes over time. A counterfactual simulation was conducted to estimate the potential population size in the absence of wetland loss from 1990 to 2021. On average, the effect of 1 hectare of wetland lost causes a reduction of approximately 1000 persons. This indicates that for the year 2021, the population was approximately 18% lower than the population that would have existed in the absence of wetland loss. This research underscores the role of wetlands in providing direct and indirect benefits to people in coastal Louisiana that are ultimately reflected in its population levels.

Keywords: population loss; wetland loss; land cover

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1. Introduction

In recent years, the continuing decrease in population in Louisiana's coastal parishes has attracted attention to the potential causes behind it (AP News, 2023; Mosbrucker, 2021; Hemmerling, 2018). From 2021 to 2022, four of the ten counties in the United States with the largest population loss were on the Louisiana coast, with decreases of 5.1% in St. John the Baptist Parish, 3.9% in Terrebonne Parish, 3.3 % in Plaquemines Parish and 2.7% in St. Charles Parish (U.S. Census Bureau, 2023). Some authors point to fewer jobs in the oil and gas sector and COVID-19 as the main causes of lower population growth (The Advocate, 2021; Hemmerling, 2018). There has been considerable debate regarding the role of diminished community resilience in the context of climate change, particularly with respect to sea level rise and tropical cyclones, which contribute to climate-induced migration (Blanchard, 2010; Hauer et al., 2019; Hemmerling, 2018). For example, Blanchard's (2010) population projections for Louisiana's parishes attributed lower levels of population exclusively to Hurricanes Katrina and Rita. However, even with crises in the oil and gas sector and an increase in the frequency and intensity of tropical cyclones hitting the Gulf Coast, the whole region has seen the fastest population growth among U.S. coastal regions since 2000 (U.S. Census Bureau, 2018; Wilson & Fischetti, 2010), with counties and metropolitan areas in Texas, Florida, and Alabama among the largest gaining and fastest growing (U.S. Census Bureau, 2017, 2022). This difference in population trends between Louisiana's parishes and other Gulf Coast counties raises the question if other drivers, such as changes in wetland cover, might be behind low population growth in Louisiana.

Louisiana's parishes are situated in the Mississippi River delta, which has the second largest river basin in the world, and like other river deltas and coastlines, is a diverse and dynamic region

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with areas of historical land gain and loss. Over the past 5000 to 6000 years, the Mississippi River Delta grew dramatically to over 10,000 km2 (Roberts 1997, Day et al. 2007 Bentley et al. 2016). In the 20th century, however, about 25% of coastal wetlands in the Mississippi Delta were lost due primarily to anthropogenic factors such as levee construction, oil and gas extraction and associated canals and impoundment, hydrological disruption, reduced Mississippi River sediment load and changes in relative sea-level (Day et al. 2007, Couvillion et al. 2017, Edmonds et al. 2023). Specifically, Louisiana's coastal parishes have undergone significant environmental changes since the 1930s, primarily due to human interventions impacting the deltaic plain (Day et al., 2007, 2019, Laska 2020, Edmonds et al., 2023, Day & Hunter, 2022). The oil and gas industry's direct and indirect impacts have caused significant chemical, biological, and physical damage (McClenachan et al. 2018; Day et al. 2020, 2022). Levees and channelization have resulted in energy and material flow alterations, leading to subsidence (Day et al. 2022; Edmonds et al. 2023), and pollution-driven toxic stress has resulted in vegetation mortality (Day et al., 2020, 2022). These factors have contributed to permanent conversion of over 485,622 hectares of wetlands to open water, more than all other U.S. States combined (Couvillion et al., 2017; Day et al., 2020, 2022).

The impact of these changes on the livelihoods, infrastructure, economy, culture, and ecosystem goods and services of coastal Louisiana has been well documented in the literature (Batker et al., 2014, Barnes et al., 2015; Barnes & Virgets, 2017; Batker & Briceno, 2022). For example, Barnes et al. (2015) conducted an economic valuation study that assessed the direct and indirect impacts of land loss on coastal Louisiana. Using georeferenced data on non-residential, residential, and network infrastructure, they calculated the capital stock value at risk of future land loss. Their research found that under a moderate land loss scenario, even without considering large storm damages, residential infrastructure replacement costs would amount to 360 million USD over a 50-year time frame. Furthermore, temporary and permanent business disruptions could result in 450 million USD in lost wages. Other studies have analyzed detailed livelihood dynamics within historically marginalized communities. One of the most emblematic examples is the resettlement effort of the Biloxi-Chitimacha-Choctaw Tribe from the Ilse de Jean Charles in Terrebonne Parish, where 98% of the territory was lost due to saltwater intrusion and subsidence that resulted from the oil and gas industry's modification of the landscape and shoreline erosion (Simms et al., 2021). In another example, Colten et al. (2018) studied the practices of non-urban communities in Orleans and Terrebonne parishes, where older residents resisted mobility while younger residents relied on inland migration as a resilience strategy. Their research found that between the 2000 and 2010 census tallies, a decrease in residents living in the same house occurred in areas where the land loss was more prominent (Colten et al., 2018). This decline in population also has an impact on the population that remain as residents, since across the United States, population declines are related to a decline of healthcare services, community services, and other benefits centered on supporting social well-being (Davis et al., 2022).

Therefore, a comprehensive coast-wide analysis is essential for understanding the impact of wetland loss on population growth and assessing whether such effects persist over time or are merely temporary shocks from which populations can recover. This analysis is crucial in coastal Louisiana, where net land loss was estimated to be approximately 483,300 hectares from 1932 to 2016 (Couvillion et al., 2017), and taking no action could result in an additional loss of up to 400,000 hectares. To address this research gap, our objective was to provide an understanding of the impact of wetland loss on population growth in coastal Louisiana using a dynamic growth model and historical data.

In addressing this objective, we examined two related hypotheses: (1) the conversion of wetlands to open water leads to population decline and that (2) this decline is persistent. To make the concepts clearer and highlight the importance of both hypotheses, Figure 1 shows the potential effects of losing a unit of wetland in an idealized parish scenario.

The idealized scenario examines a parish composed of wetlands, open water, and a category representing all other land cover types. Year 1 serves as the analysis starting point, with solid lines depicting historically observed population levels and growth. The dashed line represents the counterfactual, illustrating the expected population trajectory without changes in growth rate (Pearl,

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Glymour & Jewell, 2016). Hypothesis 1 suggests that the conversion of wetlands to open water, occurring in year 2, impacts population growth. Hypothesis 2 investigates whether the population would return to the original counterfactual trajectory in year 3, when no further wetland conversion takes place, indicating a temporary effect of wetland loss on population growth, or if it will remain at a permanently lower level, signifying a persistent effect.

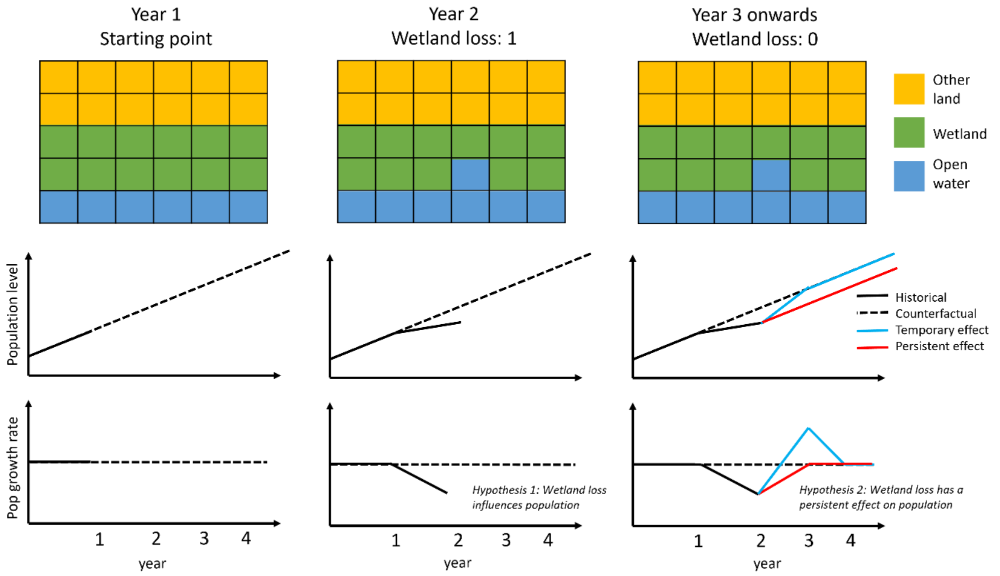

Figure 1. Illustration of the effects of a one-unit wetland loss on the population of a parish in an idealized scenario. The top panels display land cover changes across different years, the middle panels present the population levels through the years (logarithmic scale for readability), and the lower panels depict the associated population growth rates. The blue line represents the temporary effect, while the red line shows a persistent shock on population growth. Solid lines represent observed data and dashed lines represent the counterfactual, i.e. no wetland loss.

2. Methods

2.1. Data collection

To investigate the relationship between population growth and wetland loss we collected data from two main sources: the U.S. Census Bureau and the U.S. Geological Survey. Data on annual estimates of population was retrieved from 1990 to 2021, for the following parishes: St. Charles, St. John the Baptist, St. Mary, Iberia, Cameron, Plaquemines, Vermilion, Orleans, Lafourche, St. Tammany, St. Bernard, Jefferson, and Terrebonne.

For changes in land cover, we collected land cover data from the Land Change Monitoring, Assessment, and Projection (LCMAP) Collection 1.3 dataset provided by the U.S. Geological Survey (U.S. Geological Survey, 2022). The products in this dataset provide a systematic geospatial monitoring of land cover and land change derived from satellite observations from January 1st, 1985, to December 1st, 2021. LCMAP uses a harmonic model and boosted decision tree classification algorithms to classify each 30 x 30 m pixel into one of the following classes: developed, cropland, grass/shrub, tree cover, water, wetland, ice/snow, and barren (Brown et al., 2020; Zhu & Woodcock, 2014).

To apply this classification at the parish level, we filtered the LCMAP data with a vector layer delimiting each parish. We then counted pixels that indicated parish-level annual areas covered by water, wetland, and "other lands", which contains the LCMAP classifications of developed, cropland, grass/shrub, tree cover, and barren. Because this dataset only shows net land gain or loss by year per parish, we additionally obtained the Land Cover Change (LCCH) sub-product from the LCMAP dataset, which tracks yearly changes in land cover at the pixel level. With this dataset, we were able

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to accurately capture the impacts of land cover change by parish rather than just looking at net value of change at the parish level.

2.2. Regression analysis

To test our hypotheses, we constructed a statistical regression model that investigated population growth as a function of changes in wetland cover to open water over time. This model was adapted from the dynamic growth equations developed by Bond et al. (2010) and Dell et al. (2012). This type of model is widely used in econometric research to perform growth rate analysis, for example, to estimate growth rate in GDP per worker as a result of GDP investments, or temperature impacts in economic growth. This empirical framework allowed us to identify 1) the strength and statistical significance of the relationship between dependent and independent variables (population growth and wetland loss), and 2) the presence of a lagged time effect, which would indicate if the impacts of wetland loss to open water are temporary or permanent. All calculations were performed using the software *R* for the following 13 parishes: St. Charles, St. John the Baptist, St. Mary, Iberia, Cameron, Plaquemines, Vermilion, Orleans, Lafourche, St. Tammany, St. Bernard, Jefferson, and Terrebonne.

To develop our adapted dynamic growth equation, we started with a population growth function (equation 1), where g_P represents the baseline growth rate of the parish P, W represents wetland lost to open water and coefficients β and γ measure the effect of wetland loss on population levels and growth rate, respectively. In other words, β measures the temporary effect of land loss on the number of people (e.g., temporary evacuation) and γ the persistent effects of losing land (e.g., definitive outmigration or the effect on decision-making regarding family sizes). The coefficient β takes an opposite sign for $W_{P,t-1}$ (i.e. the wetland loss one year before) because a temporary effect by definition is one from which one can fully recover the following year (see Figure 1, bottom-left panel).

$$g_{P,t} = g_P + (\gamma + \beta)W_{P,t} - \beta W_{P,t-1} \quad (1)$$

Given that this dataset contains repeated observations for individual parishes over several years (also known as *panel data*) (Baltagi, 2008), we were able to estimate the model represented in equation (1) with a regression analysis by adding two variables symbolizing parish-fixed effects (θ_p) and year-fixed effects (θ_t), which helped us capture the differences between individual parishes and time-dependent variations in our model. Further, we included loss of areas with infrastructure (e.g., areas covered by residential, commercial, or industrial structures) to open water (I) as a covariate to account for the direct impact of flooding on human infrastructure. This variable is closely related to wetland loss to open water, and not considering it in the analysis could result in overestimating the wetland loss coefficient. Therefore, the estimated regression was:

$$g_{P,t} = \rho_0 W_{P,t} + \rho_1 W_{P,t-1} + \mu I_{P,t} + \theta_P + \theta_t + \epsilon_P \quad (2)$$

In the resulting equation (2), ρ_0 is the sum of coefficients β and γ shown in equation (1), which represents the contemporaneous effect that wetland loss has on population growth. Adding up ρ_0 and ρ_1 yields the persistent effect γ, and ϵ_P is the error term clustered by parish.

Using the LCCH product from the LCMAP Collection, which records pixel-level changes in the land cover dataset, we estimated regression (2). We specifically selected those pixels categorized as wetland and developed. LCMAP defines pixels classified as wetland as "Lands where water saturation is the determining factor in soil characteristics, vegetation types, and animal communities. Wetlands are composed of mosaics of water, bare soil, and herbaceous or wooded vegetated cover" (U.S. Geological Survey, 2022, p. 4), while the developed class represents:

> areas of intensive use with much of the land covered with structures (e.g., high-density residential, commercial, industrial, mining, or transportation), or less intensive uses where

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the land cover matrix includes vegetation, bare ground, and structures (e.g., low-density residential, recreational facilities, cemeteries, transportation/utility corridors, etc.), including any land functionality related to the developed or built-up activity. (U.S. Geological Survey, 2022, p. 4)

In this context, the variable W represents the area of wetlands converted to water as a percent of "other land" in the parish. The variable I represents the area of developed land as a percent of "other land". We defined "other land" as the sum of all land covers in LCMAP that are neither wetland nor open water. Having the change as the percentage of developed land and wetland for each year as a proportion of the total other lands cover allowed us to measure the effects of proportional changes.

We used the values for coefficient γ, which represents the persistent effects of wetland loss on population growth, to estimate the counterfactual, meaning the population growth that would have happened if there had been no wetland loss since 1990 (Pearl, Glymour & Jewell, 2016). We also calculated the relative (compared to the 2021 population) and total cumulative population loss for each parish from 1990 to 2021. Furthermore, we conducted a Monte Carlo simulation to generate 10,000 counterfactual population trajectories and test the sensitivity of the results to the uncertainty in the estimated coefficients (Robert & Casella, 2010). To achieve this, we drew random samples from a normal distribution that used the coefficient estimate and standard error of the regression as the mean and standard deviation, respectively. This process allowed us to re-calculate annual changes in population growth for each parish.

4. Results

4.1. Regression analysis

We found that the null hypothesis, in which developed wetland loss does not affect population growth, was rejected with a confidence of 95% (Table 1, Model 1). This shows that, while many factors may affect population rate of change, wetland loss is a key driver affecting change rates in Louisiana's parishes. From the second model (Table 1, Model 2), the results show that the sum of coefficients for wetland loss is $\gamma_{=} - 1.49$, with a p-value of 0.0005, suggesting that the conversion of wetlands to water has a persistent negative impact on population rate of change. This implies that losing a wetland area proportionate to 1% of the area classified as "other land" has a lasting impact on the population growth rate for that year, leading to a 1.49 percent points decrease.

Table 1. Results from the regression analysis of the two models.

	Dependent variable	
	Population growth (%)	
	Model 1	Model 2
Wetland loss (%)	-1.749** (0.801)	-0.961** (0.316)
Wetland loss lag (%)		-0.586*** (0.066)
Fixed effects	Parish and year	Parish and year
Covariates	Developed land loss and total "other land" cover	Developed land loss and total "other land" cover

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Observations	403	403
R2	0.472	0.563
Adjusted R2	0.406	0.507
Residual Std. Error	4.615 (df = 357)	4.206 (df = 356)
Note		***p<0.1; **p<0.05; ***p<0.01**

Interpreting the effects of wetland loss by looking at the estimated coefficient of the regression analysis is not straightforward due to the distinct proportions of wetland area to other land in each location. To illustrate these individual impacts, Table 2 presents the corresponding values for each parish. For example, in Cameron Parish, the average decrease in population growth rate is 0.64 per hectare of lost wetland. For all studied parishes, this decrease in population growth rate ranges from –0.44 (Terrebonne Parish) to –34.79 percent points (St. John the Baptist Parish). Moreover, since starting population levels and baseline growth rates differ across parishes, the impact of the gamma coefficient on population levels varies as well. Table 2, Column 2, shows the number of people lost in each parish for every hectare of wetland loss, reflecting these unique effects. The mean loss of population per hectare of wetland loss ranges from 6 (Cameron Parish) to 9252 persons (Orleans Parish) for 2021. This reflects the great differences in population in these two parishes.

Table 2. Effects of wetland loss in each parish.

Parish	**Mean change in population growth by 1 hectare of lost wetland (Percent points)**	**Mean loss of population per hectare of lost wetland (# of persons)**
Cameron	-0.64	-6
Iberia	-4.14	-29
Jefferson	-3.88	-887
Lafourche	-1.14	-19
Orleans	-11.59	-9252
Plaquemines	-0.47	-24
St. Bernard	-2.87	-869
St. Charles	-5.70	-92
St. John the Baptist	-34.79	-582
St. Mary	-2.98	-32
St. Tammany	-8.54	-1377
Terrebonne	-0.44	-31
Vermilion	-2.32	-11
Mean value	-6.12	-1016

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The results of the population counterfactual analysis (i.e., population trajectory without wetland loss) show how population levels would have changed if there had not been wetland loss from 1990 to 2021. For each parish we calculated the difference between its counterfactual trajectory and the observed population as a percent of the observed population each year. For example, Cameron Parish has a significant loss of population that increases as the counterfactual diverges from the observed trajectory (Figure 2, left). Some parishes would have had a small difference of additional population compared to the observed levels in 2021, such as St. John The Baptist (1.37%), St. Tammany (1.53%) and Iberia Parish (2.55%), while Cameron, Plaquemines and St. Bernard Parishes show a difference of 62.72%, 154.32%, and 249.26%, respectively (see Figure 2, right). This stresses the persistent effect of wetland loss in population growth.

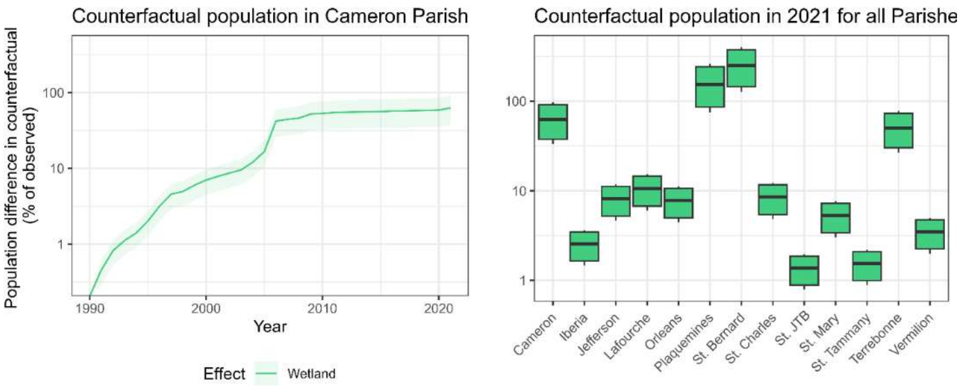

Figure 2. Left: Population difference from counterfactual model in relation to observed data for Cameron parish. Right: Population difference from counterfactual model in relation to observed data for the year 2021 for each parish (Table S1).

Overall, the counterfactual analysis for the whole period 1990-2021 demonstrates that the cumulative loss of population for all parishes yields a total of 294,671 lost population in 2021. The parishes that lost more population with respect to the counterfactual estimates for the whole period are St. Bernard, Terrebonne, and Jefferson (Figure 3, left). The Monte Carlo simulation allowed to test the sensitivity of the results to the uncertainty in the coefficients, yielding a mean value of -294,863 lost population for 2021 for all the parishes, with a 1% to 99% quantile range of -246,981 to –344,920 (Figure 3, right).

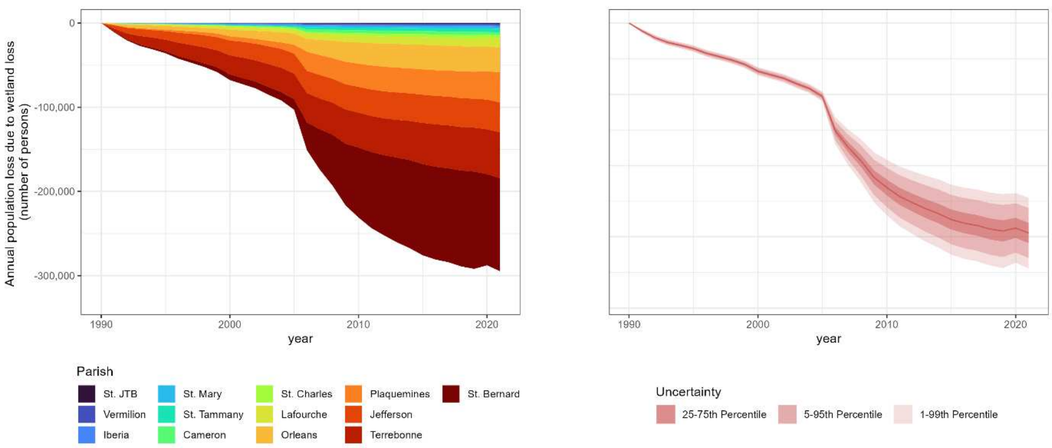

Figure 3. Left: Cumulative difference in population loss due to wetland loss for 13 parishes. Right: Monte Carlo Results for the total difference in population loss, shaded areas show the 25% to 75% quantile, 5% to 95% quantile, and 1% to 99% quantile of 10,000 simulations.

5. Discussion

The results of our study demonstrate that wetland loss has a negative and significant effect on population levels and rate of change across Louisiana's coastal parishes. Moreover, we found that this effect is persistent over time, meaning that even if wetland loss stopped happening, the initial shocks are sufficient to maintain that effect in the long-term. Controlling for year-fixed effects effectively removes land loss shocks that are common to all parishes, such as those that could be caused by temporary hurricane impacts, indicating that direct hurricane shocks would cause only temporary population decline in the absence of wetland loss. This seems to be the case for the U.S. Gulf of Mexico coastline which has experienced hurricane impacts, but long-term rapid population increases, higher than the U.S. Pacific or Atlantic coastlines (U.S. Census Bureau, 2018; Wilson & Fischetti, 2010).

Some years show extraordinary losses in population levels with respect to the counterfactual. These years are associated with the impact of hurricanes Katrina and Rita in 2005 and hurricanes Laura and Zeta in 2020. While Gulf-wide hurricanes outside of Louisiana result in short-term population decline with recovery and rebuilding and the restoration of the population, the indirect effect of hurricanes in association with other factors acting through wetland loss in Louisiana causes permanent declines in population. Moreover, while hurricanes bring sediment and benefits to healthy wetlands, supporting coastal and deltaic land building, the hydrological disruptions caused by the leveeing of the Mississippi River and pervasive hydrologic alterations caused largely by oil and gas industries have reversed this effect (Day & Hunter, 2022; Morton & Barras, 2011; Day et al. 2020, 2022).

The counterfactual simulation further demonstrates the effect of wetland loss on population rate of change across parishes and across time, with a high degree of certainty. We found that for parishes like Plaquemines and St. Bernard, the population in 2021 would have been 2.5 and 3.5 times, respectively, the observed population if there had not been wetland loss. Furthermore, the Monte Carlo analysis shows that the current population is likely 18% smaller than it would have been without wetland loss from 1990 to 2021 in Louisiana's coastal parishes. The magnitude of these changes is not uncommon in regions that have been systematically affected by extractive industries across the globe (e.g., Pallagst & Al, 2009) and reflects the findings of studies in coastal Louisiana that have measured cumulative damages as a function of community resilience (Kim et al., 2018).

Loss of wetlands can cause population decline through several direct and indirect mechanisms. Authors have identified direct impacts in the form of reduced protection against flooding and storms (Li et al., 2018; Twilley et al., 2016), as well as economic loss from impacts on nursery areas for fisheries (Nicholls, Hoozemans & Marchand, 1999). A less direct mechanism involves understanding the populations' motivations and how they perceive the risk or the damage that losing wetland could bring to their communities (Colten et al., 2018). To fully understand the mechanisms underlying change in population dynamics caused by wetland loss, it is important to develop parish-level or community-level models that incorporate the role that wetlands play in factors that inform population growth, such as those related to birth rate and migration.

The hydrological dynamics of the Mississippi River Delta contributed to land gains on the coast of Louisiana until the 1930s, however, since then the region has seen a rapid decline in wetlands (Couvillion et al., 2017). This indicates that a longer time series (for example, from 1930 to 2022) will likely find a greater impact of land loss on population migration.

While several studies have analyzed the persistent nature of temperature shocks in economic metrics such as gross domestic products (Bastien-Olvera et al., 2022; Burke et al., 2015; Dell et al., 2012; Newell et al., 2021), this study looks at the relatively unexplored question of persistent damages of wetland loss on population growth in coastal Louisiana, a question that is of particular interest in regions that are at risk of losing land due to oil and gas extraction, wetland collapse, sea-level rise, or a combination of anthropogenic and natural factors.

Conclusions

This study highlights the significant impact of wetland loss on population decline and negative growth rates in Louisiana's coastal parishes. Our findings indicate that it is possible to distinguish a persistent effect of changes of wetland to open water on population levels as well as population growth rates, leading to a cumulative effect over time. The simulation results show that the current population in Louisiana's 13 coastal parishes is likely 18% lower than it would have been without wetland loss from 1990 to 2021. This highlights the key role that wetlands play in influencing population growth.

This impact is more evident considering that, unlike Louisiana's coastal parishes, the rest of the Gulf of Mexico region has seen the greatest increase in population among coastal regions, with a growth of 24.5% during the period of 2000 to 2016 (Cohen, 2018). This has been more evident in counties from Texas and Florida (U.S. Census Bureau, 2017; 2022).

Further research is needed to understand the mechanisms that link wetland loss and population decline, especially in a context where an increasing number of communities might have to be relocated in the future due to relative sea-level rise, ecosystem collapse, or a combination of anthropogenic and natural processes. Modeling across a longer time series, for example from 1930 to 2022, could provide greater insights into the dynamics of population and wetland loss in coastal Louisiana. Studies such as ours are essential to inform good relocation practices currently underway (e.g., Simms et al., 2021) and coastal wetland restoration at scale (CPRA, 2017) to effectively present policymakers with tools that allow them to shape restoration plans.

Data Availability Statement: Data processing, regression estimates and simulations available at: https://github.com/BerBastien/Wetland-loss-effects-on-population-growth.

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