Blooming algae and falling returns on investments. The Swedish housing market in the face of biodiversity risk

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Abstract:

This study aims to shed light on the implications of biodiversity risk for the Swedish residential housing market. While most of the previous academic literature and national and international financial supervision focused on transition and physical risks as the main channels of climate's impact on housing prices, this study reveals the significant role that biodiversity risk can play. In Sweden, higher temperatures, discharges of nutrients from agricultural activities and changing raining patterns have rendered algae blooms a frequent presence in the country's lakes, streams and seashores. By adopting a repeat-sales approach over the housing transactions that occurred in the country between 2005 and 2021, it is found that each additional appearance of blooming algae reduced returns on investments by 0.5% on average. Additional identification strategies confirm that the marginal impact of one additional blooming alga has a very small impact, while the first appearance can reduce the return on investment by about 5.5% on average. The results are robust to several forms of sensitivity analysis, such as including information on housing renovation and excluding assets with short holding periods. Concerns over measurement errors and endogeneity of the distribution of the algae are addressed with the use of instrumental variables (IVs), which confirm the validity of the findings and reveal an even stronger impact. The results of this study are relevant for a large number of economic actors, among these private households, investors and policymakers, and present alternative channels, other than natural hazards, through which climate change can impact housing markets.

Keywords: blooming algae, housing prices, returns on investment, Sweden, biodiversity risk

JEL-codes: Q5; R3; C1

1. Introduction

Increasing average global temperatures in the last decades have been shown to impact the appearance and the quality of natural environments. An increasing number of areas around the globe are experiencing desertification (Jain *et al.*, 2024), or are struggling to deal with invasive alien species that benefit from the expansion of their natural habitats (Bodey *et al.*, 2023). Certain plants and insects are among these. Habitats are also changed by direct human actions, beyond the sole impacts of a warmer environment. Sitting at the intersection between changing rain patterns, higher temperatures and discharge of by-products of human activities, certain species of algae have particularly benefited from mutated natural habitats. These organisms thrive both in higher temperatures and in the presence of nutrients, such as phosphorus, usually employed for agricultural purposes (Sildever, Stewart and Tesson, 2024). The expansion of these algae has been experienced both in salty water, along the coasts of several marine locations, and in fresh waters such as streams, lakes and rivers (Fang *et al.*, 2022), with Europe representing one of the hotspots of such a process (Hou *et al.*, 2022).

The presence of algae has the potential to produce economic and financial consequences for several sectors of economic activities. First and foremost, fishing and aquaculture are particularly exposed to the increasing presence of algae (Wolf, Georgic and Klaiber, 2017; Sakamoto *et al.*, 2021). Recurrent algae blooming episodes have, for instance, been linked to decreased attractivity for fishing activities in certain areas of the United States of America (Wolf, Georgic and Klaiber, 2017). Fishermen are not willing to renew or purchase new licenses to operate in waters that are frequently affected by algae blooms. However, while, to some extent, fishing and aquaculture are often carried out using movable capitals, i.e. the activities can be moved to other areas provided that these guarantee a suitable environment, some economic activities are characterized by immovable, fixed and illiquid capitals. Algae blooms have been linked to lower returns in hospitality activities, for instance (Alvarez *et al.*, 2024). These types of businesses cannot be easily transferred and are therefore exposed to the full impact of the degradation of the quality of the surrounding water bodies. With respect to this, real estate is another economic sector that, by nature, cannot avoid exposure to climate risk by relocating. Policies such voluntary or mandatory properties buyouts have been adopted in some cases to incentivize relocation but a clear understanding of the costs and of the benefits of these is still lacking (Curran-Groome *et al.*, 2021). The impact of climate risks on the real estate sector is well researched from both a physical and a transition climate risk perspective, but little is still done and understood regarding exposure to biodiversity risk. Algae blooms provide a perfect example of such a risk. Their presence does not cause any damage to the integrity of the buildings and is not the result of an attempt to comply with environmental regulations or to reduce carbon footprints, and therefore escape the traditional definition of physical and transition climate risks (Giglio *et al.*, 2021). However, they alter the quality of the surrounding environment and may render certain assets less attractive for potential buyers. The presence of blooming algae in water bodies has the potential to revert a well-established evidence of positive impact of water amenities on housing prices (Larson and Perrings, 2013). It should be noticed that the standard definition of biodiversity risk in the finance and economics literature refers to the negative consequences that a loss in biodiversity may cause to economic systems (Mies, 2025). What is argued in this study is that changes in the distribution and the frequency of certain species, and not exclusively losses but in some cases even expansions, should also be accounted for when considering the costs that climate change may impose on societies. The potential impact of blooming algae on the housing prices of the surrounding markets has, to some extent, been investigated by some previous studies. Wolf et al (2022) focus their attention on the specific case of Lake Erie, in the United States, a lake whose water quality has severely deteriorated in the past decades, due to the presence of high levels of nutrients from human activities in the rivers that flow into it. By relying on satellite images to spot the blooming algae, the authors make use of an instrumental variable approach and identify significant negative effects on housing prices up to 1,2 miles from the coast of the lake. In particular, the results suggest that each additional μg/L of algae in the water of the lake is associated with a 1.4% decline in housing prices. Additional evidence from algae blooms in lakes in the USA is provided by Wolf and Klaiber (2017), which find properties within 600m from affected lakes to experience an average 22% drop in final selling prices. In Ohio only, the authors argue, the total cost of housing values depreciation due to algae exceeds $51 million. Agricultural activities in the surroundings of the water bodies are identified as the main responsible driver of the presence of algae by Osseni et al. (2021) too. The authors assess the effect of the presence of algae in the coastal water of Britanny, France, one the most agriculturally intense regions of the country, by relying on a hedonic ordinary least square (OLS) method. The estimated elasticity between housing prices and the distance from the polluted coasts is computed at 0.058%: a 1% increase in the distance increases the prices by 0.058%, reverting long-standing understanding in hedonic price models that proximity to the sea has positive marginal returns on housing prices (Koramaz and Dokmeci, 2012). The authors caution that a robust method should be employed to produce robust results, as topographic characteristics may both be driving the presence of the algae and affect housing prices. Still in Europe, the only other study I am aware of is another assessment of the impact of algae blooms in coastal environments. Lamas Rodríguez et al. (2023) focus their attention on the case of San Pedro del Pinatar, in Spain, a touristic coastal city that has experienced recurring episodes of algae blooms. By comparing prices in affected and free areas with similar characteristics, the authors provide evidence that the presence of the algae implied a 43% lower return on investment in the affected housing market. Combining a repeat-sales approach with an hedonic OLS, Bechard (2020) reveals that properties in south-western Florida located within 5 miles from areas affected by algae blooms experienced a 4.71% discount in the months when these occurred, as opposed to other algae-free months. Further evidence of the impact of algae on the local housing market in Florida is provided by Bechard (2021) who finds affected properties within 1 mile from the coast to sell for a 20% discount. Zhang et al. (2022) focus on the specific case of inland lakes in the contiguous USA and retrieve data on the spatial distribution of algae blooms by relying on satellite imagery. This application focusing on the whole country reveal certain degrees of heterogeneity in the impacts, with a 10-percentage points increase in the annual occurrence of cyanobacteria being associated with a price drop of 4.3% in the Northeast and 3.3% in the Southeast. While no evidence of economic impact, to the best of my knowledge, has yet been produced in the case of Northern Europe, scientific evidence is mounting that the issue is becoming a pressing one in this part of the world too. By leveraging on the availability of satellite imaging, Karlson et al. (2022) identify an increasing trend in the total surface area of blooming algae in the Baltic Sea during the 2002 – 2020 period. The presence of blooming algae in Norther Europe, and in particular in Sweden, has also been detected in inland lakes, and such an occurrence has prompted research efforts towards the identification of measures that could help deal with the problem, such as wetlands (Borgström, Hansson and Sjöstedt, 2022). Previous research in Sweden has also called on further research to attempt to provide a quantitative measure of the economic implications of the presence of the algae (Karlson *et al.*, 2022).

The goal of this paper is to investigate the impact of algae blooms on the real estate market of Sweden and fill the void that the previous literature has identified in the quantitative estimation of the impact of algae on economic variables in Northern Europe. It provides significant contributions to the previous literature by examining, for the first time, the impact of algae in lakes, rivers and along the seashore in a European context. So far, all European studies only focused on coastal environments. The dataset of algae samples on which this paper builds allows to contribute to the literature in another way: it represents the first study where a repeat-sales model is used together with an instrumental variable (IV) approach to address the following research question:

RQ) Is there any evidence of impact of the presence of blooming algae on housing prices in Sweden?

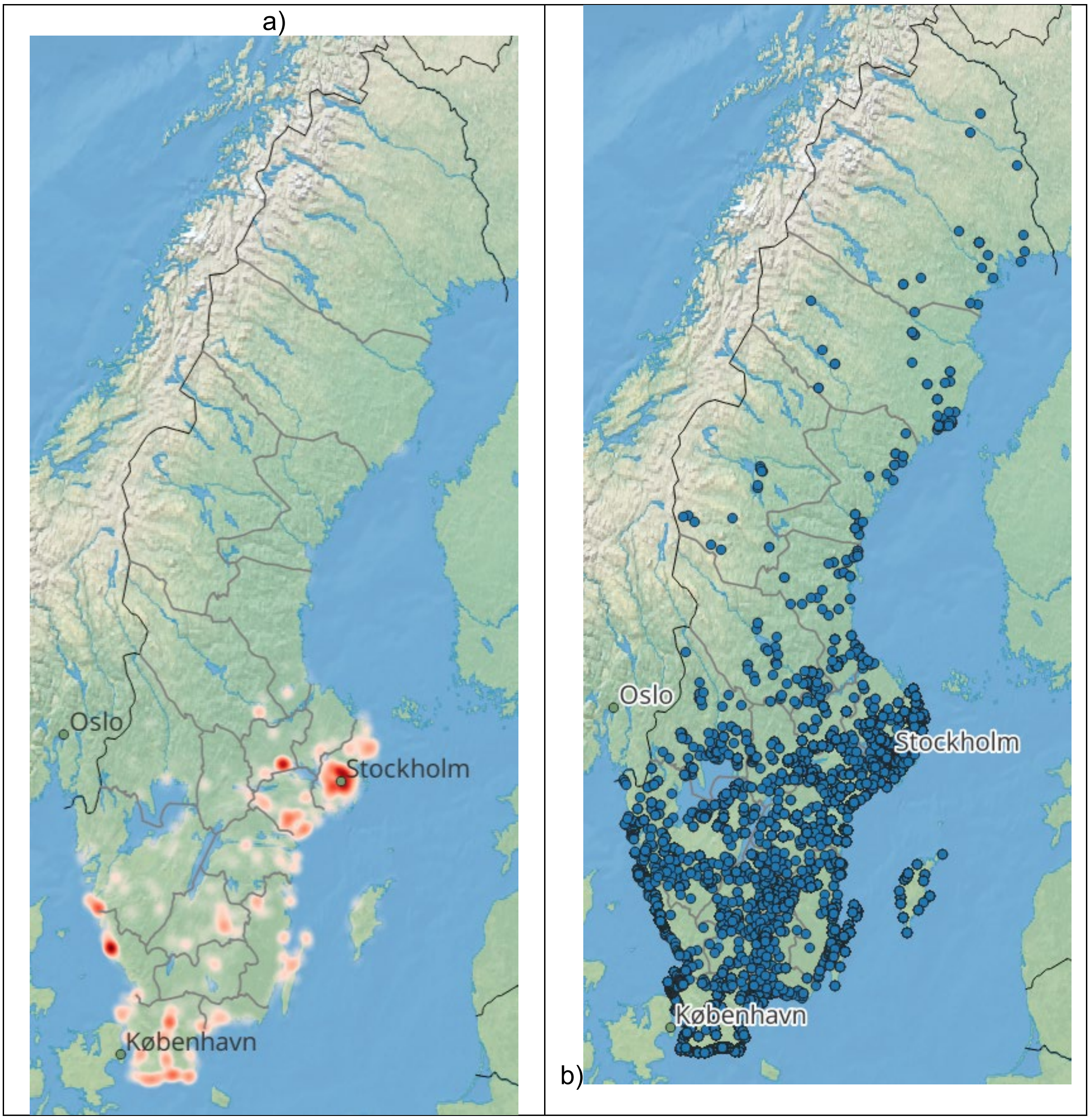
The rest of the paper is organized as follows: the Methods and Data section introduces the dataset on which the analysis is built and justifies the decision to employ a repeat-sales model. The Results section presents the main results from addressing the RQ and performs some robustness stress to assess the reliability of the results. The Discussion section discusses the implication of the results and benchmark them against the previous evidence. The Conclusions section concludes the paper and points towards directions for future research.

2. Methods and data

The dataset this study builds on, provided by Svensk Mäklarstatistik AB, is composed of real estate transactions that occurred in Sweden during a 17-years period between 2005 and 2021. Each individual transaction contains information on the asset such as location, including the geographic coordinates, the size of the living area, the type of assets (villas, apartments, etc.), the final selling price, in 2005 Swedish crowns (SEK), the contract date, etc. The initial dataset, containing more than 2 million observations, is cleaned to retain a suitable corpus of observations by dropping entries that miss essential information such as the final selling price or the geographical coordinates. The nature of the approach adopted in this study, i.e. the repeat-sales model, requires further adjustment in order to construct the final dataset. First of all, assets should be uniquely identifiable. This means that for every single asset, it should be possible to understand if it was sold more than once during the 17-years period that the dataset spans. This is particularly problematic with apartments, for which the provided geographic coordinates represent the centroid of the building where they are located. Even when using additional information such as the size of the living area and the floor number, one cannot rule out that multiple apartments in the same building could be located on the same floor and with the same size of the living area. Geographic coordinates can therefore be used to uniquely identify only villas and one- or two-family houses. The restriction of the dataset to only include these types of assets, it can be argued, does not constitute a problem. First of all, this practice represents a common approach in studies evaluating the impact of climate risk on housing prices, often supported by the idea that this type of assets should be more exposed to the consequences of a changing climate (Meldrum, 2016; Wolf and Klaiber, 2017). Moreover, the research question addressed in this study is better investigated in rural areas where, for instance, most of Swedish lakes and streams are located. Given the little relevance of the research question for urban areas, excluding apartments from the final dataset does not pose any issue. Lastly, most of the assets in the proximity of lakes are villas, holiday homes and single-family houses. An ideal control group should be formed of assets that resemble those in treatment group, and hence, in this case, other villas and holidays homes.

Observations on the presence of algae in lakes, rivers and salty waters in Sweden are made available by the Swedish Agency for Marine and Water Management (*Havs- och Vattenmyndigheten, HoV*). Each observation in their dataset, which span a period of 35 years between 1991 and 2025, reports the date in which the sample was collected, the venue and the result of a test assessing the presence of blooming algae. A total of almost 11,000 samples tested positive to the presence of blooming algae in the last 35 years across the whole country. Figure 1 shows the geographical distribution of the observed blooming algae episodes. The seashore around Stockholm in the east, the southern tip of the country and the coastline around Gothenburg in the west represent the largest hotspots by the sea. A significant presence of the algae is also detected inland, around the numerous lakes, rivers and streams of the country. The regions around the Mälaren lake, right west of the capital Stockholm, all display high concentrations of episodes of blooming algae. No region south of Stockholm seems to have been spared by episodes of blooming algae. North of it, Västerbotten is also a significant hotspot of coastal observations of blooming algae.

Figure 1 shows the distribution of the almost 11,000 samples between early 1990s and 2025 that detected blooming algae, as a heatmap in a) and as points in b)



The choice of the model to address the research question outlined in this study is driven by considerations on the nature of the event at study. Each venue in the dataset provided by HoV had the potential to be tested multiple times and to return positive results to algae tests multiple times through the years. This introduces the issue of multiple treatment periods. Difference-in-Differences (DiD) approaches, the most common ones employed to investigate quasi-natural experiment research questions pertaining the impact of climate change on housing prices, have recently benefited from progresses that allow for multiple treatment periods. However, in this case the composition of the treatment and the control group is also changing. An asset could be considered part of the control group with respect to a single appearance of blooming algae but may then move to the treatment group few years later if algae appear in its proximity. In addition, DiD imposes stringent assumptions regarding the parallel trend trajectories of prices between control and treatment groups. With observations coming from the housing market, which is notoriously affected by seasonality patterns, it may be difficult to find instances where these assumptions hold (Votsis and Perrels, 2016). Lastly, Baker et al. (2022) reveals how the use of staggered DiD, i.e. when the treatment period occurs at different time for different groups, may often lead to inconsistent estimates. Alternative methods have been employed in literature that may help deal with multiple treatments. A regression discontinuity design (RDD) is, for instance, adopted by Wilhelmsson et al. (2021) to assess the impact of shootings on housing prices in Stockholm. In this case too, multiple treatment periods are found but the authors isolate each event, treat it as independent and fit a model for each shooting. Isolating every episode of algae blooming and fitting a model for each of these is not a feasible solution in this study as in some cases the number of observations may be too low to produce reliable estimates, introducing issues with the power of the test. In addition, the approach to assess the appearance of every algae as a single event to test hypotheses on is very likely to introduce a multiple hypothesis testing issue, where the probability of false rejections, i.e. the identification of statistically significant results when they actually are not, is significantly higher than what is assumed by the significance level adopted (List, Shaikh and Xu, 2019). A repeat-sales approach instead, the one preferred in this study, fits only one model, relies on the benefits of a large sample and therefore is more likely to validate the assumptions required to produce consistent estimates (Wooldridge, 2018). The issue of multiple treatment periods and multiple events in housing studies is addressed by Kelly and Molina (2023) too, and the authors build a case similar to the one just presented here on why the repeat-sales method can provide a suitable solution. The method is also the one behind the extensively used Case-Shiller Index (Case and Shiller, 1987). By observing the same assets being transacted several times, it is also possible to offer a better control of their time-invariant characteristics while obtaining more precise estimates of the factors that have changed between two consecutive sales. After these considerations on the nature of the events studied, the availability of information from the dataset on housing transactions and the need to provide reliable and robust estimates, a repeat sales model is deemed the best strategy to address the research questions outlined in the Introduction. Additional issues independent of the model of choice such as potential endogeneity and measurement errors in the variable of interest are addressed later on in the manuscript via an instrumental variable (IV) approach.

As the name itself suggests, the idea behind the repeat-sales approach is to exploit the fact that, given a large timespan in the transactions dataset, one can monitor the evolution of prices for each individual asset. The goal is then to construct a set of observations where each entry is constituted by information on the asset, the price for which it was sold, and the price for which it was sold the previous time. That is, each entry has information on two consecutive transactions involving the same asset. This has, of course, the main drawback of limiting the number of observations available for the estimate, as an asset is required to have been sold at least twice to make it to the final corpus. This reduces the initial dataset from about 2 million observations to slightly above 70,000.

The estimation strategy is first carried out following the format of Equation (1):

$$\Delta ln(price_{i,t,T,j}) = \alpha + \boldsymbol{\beta X}_i + n\_algae + \rho W_i \Delta ln(price) + \gamma_j + \epsilon_i \qquad (1)$$

Where $\Delta ln(price_{i,t,T,j})$ is the difference in final selling prices for asset i between two consecutive transactions occurring at time t and T in postal code j. These prices have been log-transformed before the computation of the difference, hence the dependent variable can be better interpreted as the return on investment, where the percentage variation between two consecutive prices is the result of an approximation of the difference between two natural logarithms. $\boldsymbol{X}_i$ is a vector of characteristics for asset i such as, for instance, the size of the leaving area, the years of the two consecutive transactions, t and T, meant to account for the natural price appreciation that is often observed in housing markets and the size of the area of the plot that belongs to the house. Additional variables are included in the original information retrieved from the transactions dataset. These include the distance from the closest lake, the distance from the closest spot where algae blooms were detected and the distance from the sea. $\rho W_i \Delta ln(price)$ represent the spatially lag variable of housing prices and γ_j is the postal code fixed effect. The impact of the algae on the return of investment from purchasing a residential asset is here estimated through the variable n_algae, a continuous variable that indicates the number of times blooming algae were detected by the closest bathing venue between two consecutive transactions. The first part of the Results section is then dedicated to investigating the significance of this term and whether the results are correlated with the number of blooming algae. It is reasonable to assume, for instance, that a single test returning positive results to the presence of blooming algae may not impact the dependent variable as much as larger number of detected algae. At the same time, once the amenity is affected by the presence of one blooming alga, additional tests confirming the presence of additional blooming algae will probably have small, if not null, marginal impacts. Such an assumption is tested in Equation (2), where a series of categorical variables are introduced to replace the n_algae control. Categorical variables controlling, respectively, for the presence of only one blooming alga, for only two, for only three and for four or more are created. The specification of Equation (2) introduces additional variables to Equation (1) to verify the hypothesis that the impact is correlated with the number of algae. The goal is to understand whether, for instance, the appearance of one alga has a different marginal impact on the return on investment than the appearance of two or three algae. Summary statistics of the continuous variable are presented in Table 1.

$$\Delta ln\left(price_{i,t,T,j}\right) = \alpha + \boldsymbol{\beta X}_i + \sum_{i=1}^{4} treatment_{t,i} + \rho W_i \Delta ln(price) + \gamma_j + \epsilon_i \tag{2}$$

The sum operator on $treatment_{t,i}$ with $t \in [1,2,3,4]$ represent the series of categorical variables mentioned above. The rest of the variables are left unaltered from the specification in Equation (1).

Table 1 Summary statistics from the transactions dataset

Statistic	N	Mean	St. Dev.	Min	Max
Contract price (SEK)	77,824	2,410,520.00	1,629,453.00	119,000	9,995,000
Living area (m^2)	77,824	120.12	40.97	10	600.00
Plot area (m^2)	77,824	1818.81	13962.03	25	986,237
Distance from closest algae bloom (m)	77,824	9,401.35	17,293.69	74.94	261,133.20
Distance from closest lake (m)	77,824	695.64	594.34	0.00	8,022.67
Distance from sea (m)	77,824	32,522.25	42,318.63	0.00	313,657.40
Number of algae	77,824	0.8379	2.107	0.00	39

3. Results

3.1 Main results

The results from estimating Equation (1) and Equation (2) are presented in Table 2, Column (1) and Column (2) respectively. Only the variables of interest to address the research question are included. The complete results for each variable in the equation are available in Table A1 in the Appendix. The validity of the approach adopted here is confirmed by the evidence that the results in Table A1 are in line with what was found in the previous literature: on average, assets located close to water experienced a higher return on investment; and so did larger assets and assets with larger plots of land available. The results in Column (1) of Table 2 reveal that the presence of algae has a statistically and economically significant impact on the return on investment. Everything else constant, the results indicate that each additional blooming alga in the surrounding water reduces the return on investment by, on average, 0.5%. Column (2) provides the results obtained from fitting Equation (2), expanding the results in Column (1) by investigating whether the marginal impact of additional algae is decreasing. With this specification, it is noted that only one single detected alga decreases, on average, the return on investment by 5.4%, everything else constant. The impact is larger the more algae, albeit only slightly, with two (three) algae causing a decrease of 5.8% (6.4%). The figures in Column (1) and in Column(2) in Table 2, while having significantly different magnitudes, reveal a similar dynamic behind the way blooming algae affect returns on investment on the housing market. Column (1) shows that each additional alga reduces the return on investment, by on average, 0.5%; while column (2) reveals that one (two) single blooming alga detected between the two consecutive transactions reduces the return by as much as, on average, 5.4% (5.8%). The difference between the coefficients in Column (2) are really small, indeed confirming that one additional detected blooming algae has a very small impact, as stated by the results in Column (1). T-tests performed on the pair-wise comparisons among the coefficients in Column (2) fail to reject the null hypothesis that there is any statistically significant difference. What the results in Column (1) show is that the marginal impact of an additional alga is statistically significant but economically small. Column (2) reveals that one single alga detected makes a large difference, about 5.5% compared to control transactions but that when two algae appeared, that difference with the control is unaffected. What the results show is that one single detected alga as the potential to severely impact the returns on investment. But after that first alga, the marginal impact of each additional blooming alga is extremely small and at times negligible. As far as the quality of the fitness is concerned, it must be acknowledged that the R^2 is significantly lower than what is normally achieved in hedonic price modeling applications. However, it suffices to say that such a lower quality of fitness must be imputed to the model employed. The value is in fact not distant from what is found in other studies based on the same repeat-sales approach (Richardson, Liu and Eggleton, 2022; Ellen and Meltzer, 2024; Holtermans, Kahn and Kok, 2024).

Table 2 Main results from Equation (1) and Equation (2)

	Dependent variable:	
	$\Delta ln\left(price_{i,t,T,j}\right)$	
	(1)	(2)
Number of algae	-0.005***	
	(0.001)	
$Treatment_1$		-0.054***
		(0.005)
$Treatment_2$		-0.058***
		(0.009)
$Treatment_3$		-0.064***
		(0.01)
$Treatment_4$		-0.059***
		(0.01)
Year Control	Y	Y
Postal Code F.E.	Y	Y
Asset Characteristics	Y	Y
Distances Variables	Y	Y
Observations	77,824	77,824
R^2	0.478	0.479
Note:	*: p<0.1,**: p<0.05,***: p<0.01	

3.2 Accounting for renovations

Underlying the application of the repeat-sales method as described in the Methods and Data section is the assumption, common to several studies from the previous literature (Beltrán, Maddison and Elliott, 2019; Bogin, Doerner and Larson, 2019), that the structural characteristics of the assets remain unaltered between the two consecutive transactions. While this assumption may sound reasonable for aspects such as, for instance, the size of the living area, it is difficult, especially with datasets spanning long periods of time, to believe that no renovation is carried out. Previous studies shed light on the bias in the results that can be introduced by ignoring the impact of renovations, an operation that has the clear potential to increase the return on investment (Bogin and Doerner 2019). This study builds on the same exact dataset that is employed by Stenvall et al. (2022), who is able to extract information on the renovation of the assets from the variable describing the year of construction. The same approach is adopted here and an additional binary variable, *Renovated*, is constructed and added to the specification in Equation (1) and in Equation (2), equaling 1 for the observations where the consecutive transactions occurred one before and one after the renovation. A full and detailed description of the approach to extract information on renovation can be found in Stenvall et al.(2022). Column (1) in Table 3 presents the results of including the information on renovation in the specification presented in Equation (1). While it is shown that the inclusion of this additional information does not impact the previous results, with each additional algae, everything else constant, reducing on average the return on investment by 0.6%, it is clear that houses that carried out a renovation between the two consecutive sales benefited from such an investment. On average, returns on investments for houses that have been renovated are found to be about 25% higher. Column (2) displays the results from fitting Equation (2) with the additional information on the renovation. It is confirmed with this specification too that the previous results are not altered as far as the marginal impact of the algae is concerned and that renovations can increase returns on investment by 25% on average, everything else being constant. The complete results from fitting Equation (1) and Equation (2) with the additional information on renovations are presented in Table A2 in the Appendix.

Table 3 Main results from Equation (1) and Equation (2) by including information on renovation

	Dependent variable:	
	$\Delta ln(price_{i,t,T,j})$	
	(1)	(2)
Number of algae	-0.006***	
	(0.001)	
$Treatment_1$		-0.054***
		(0.005)
$Treatment_2$		-0.058***
		(0.009)
$Treatment_3$		-0.064***
		(0.013)
$Treatment_4$		-0.059***
		(0.01)
Renovated	0.252***	0.253***
	(0.07)	(0.076)
Temporal controls.	Y	Y
Postal Code F.E.	Y	Y
Observations	77,824	77,824
R^2	0.478	0.479
Note:	*: p<0.1,**: p<0.05,***: p<0.01	

3.3 Short ownership

The nature of the residential markets assessed in this study is mostly rural, being made of summer houses and cottages or one- and two-families houses on the outskirts of cities. Professional investors seeking rapid and high returns from residential investments tend to usually target larger urban areas. Given that the dataset of transactions on which this study builds does not contain information on the reason behind the decision to sell, it is impossible to rule out the possibility that some of the transactions were made by investors seeking a quick and high return on investment. These sorts of transactions are usually characterized by low holding periods, where the asset is purchased and sold within few months, and generate a return that is significantly higher than the ones observed on the market (Wong and and Chau, 2022). Other reasons may be behind the need to sell an asset when this was purchased only shortly before, such as the need for liquidity. It is reasonable to assume that, irrespective of the reason behind the short holding period, such situations have the potential to bias the results of the study. I therefore proceed by filtering out observations that were held for less than one year, following, for instance, the standards adopted by Dundas (2017), who sought to deal with the same concern. By doing so, the initial dataset is reduced to 66,815 observations. Table 4 displays the results from fitting Equation (1) and Equation (2) with this restricted dataset in Column (1) and in Column (2) respectively. The complete results of the regressions are contained in Table A3 in the Appendix. Overall, while the direction and the statistical significance of the impact of the presence of algae on the return on investment are confirmed, the magnitude is here estimated to be smaller than before. Each additional alga is here estimated in Column (1) to decrease the return on investment by 0.4% on average. The results from Column (2) suggests that the one initial alga has, on average, a 5.8% negative impact on the return on investment, but that additional algae has a very small marginal contribution.

Table 4 Main results from Equation (1) and Equation (2) by excluding transactions with low holding periods

	Dependent variable:	
	$\Delta ln(price_{i,t,T,j})$	
	(1)	(2)
Number of algae	-0.004***	
	(0.001)	
$Treatment_1$		-0.058***
		(0.006)
$Treatment_2$		-0.05***
		(0.009)
$Treatment_3$		-0.06***
		(0.013)
$Treatment_4$		-0.044***
		(0.011)
Temporal controls.	Y	Y
Postal Code F.E.	Y	Y
Observations	66,815	66,815
R^2	0.463	0.464
Note:	*p<0.1, **p<0.05, ***p<0.01	

3.4 Addressing potential endogeneity

One of the assumptions on which the estimation of Equation (1) and Equation (2) in their current forms rest is that of no correlation between the independent variables and the error term. While housing characteristics such as the floor size and the number of rooms and the geographical features of the area such as the distance from the closest lake should not pose an issue with respect to this matter, it is not possible to rule out the possibility that the presence of blooming algae may be driven by other factors that may influence housing prices and returns on investment. When these factors are not properly accounted for, an endogeneity issue may bias the estimated coefficients. The presence of algae has, for instance, been linked to intense agricultural and livestock activities in the surrounding areas (Chakraborty *et al.*, 2017) and it is possible that these may have a direct impact on housing prices. The existence of such a correlation gives rise to inconsistent estimators. Addressing endogeneity in the variable controlling for the presence of algae is therefore essential to guarantee that the estimates adhere to the assumptions. In addition, measurement errors in the presence of algae, with some of these being potentially missed or misreported, may further exacerbate the need to adopt a stronger identification strategy for Equation (1).

Instrumental Variables (IV) and the 2 stages least squares method (2SLS) used to estimate these, have been proven to be a valid tool to address endogeneity and measurement errors concerns. An ideal variable to be used as instrument for an endogenous independent variable must be relevant, in the sense that the instrument is correlated with the endogenous variable to be instrumented, and exogenous, implying that the instrument is not correlated with the error term. A relevant and exogenous instrument can therefore be used to estimate the exogenous variations in the endogenous variables and provide a reliable estimate of the coefficient (Wooldridge, 2018). The issue of endogeneity of the presence of algae has been addressed and discussed also in the previous literature (Moore *et al.*, 2020), where measurements on the content of phosphorus and nitrogen were found to represent valid instruments to solve the problem. The dataset on algae observations by HoV that are employed in this study does not provide information on the content of nutrients in the water. I therefore turn to the dataset provided by the Swedish Meteorological and Hydrological Institute (SMHI) which partitions the country by sub-catchment areas and returns the values of phosphorus and nitrogen in these. Each observation in the dataset is therefore mapped to the catchment area it belongs to and the values of phosphorus and nitrogen in the waters of this are extracted. In order for phosphorus and nitrogen contents in the water to be a valid instrument for the IV approach one must guarantee that the only way through which these instruments affect the dependent variable is through the exogenous one, ie the presence of blooming algae. That is to say, nitrogen and phosphorus should not have any impact on housing prices but through the fact that their presence increases the likelihood of blooming algae. Dissolved nitrogen in waters is tasteless, colorless and odorless and should not therefore visibly impact the quality of the water other than through providing a favorable environment for blooming algae (Khanfar, 2010). The same properties are shared by phosphorus when dissolved in water (Passioura, 2002). A third variable is then added to the approach as instrument, the temperature of the water. In particular, a variable *Water Temperature* is added that accounts for the number of days when the measured water temperature was higher than 20C, in accordance with the findings from the literature that temperatures above this threshold constitute the optima environment for blooming algae (Singh and Singh, 2015). Given the properties of the nutrients that stimulate algae growth and the fact that a potential homebuyer would not be able to assess the temperature of the water surrounding the asset on sale, it is argued that the only way in which these variables should influence housing prices is through the provision of an environment that foster algae growth. The addition of the water temperature variable, compared to what was done in the previous literature, is here promoted with the idea to prevent issues that arise when the employed instruments are only weakly correlated with the endogenous variables. While it can be argued that sunny and warm days may have an impact on housing prices, it is unlikely that a potential buyer is aware of the temperature of the water in the surrounding lakes and streams. Sunny and warm days on the day the house on sale is visiting may impact prices, but these one-day conditions are not necessarily reflected in warmer waters. It is not reasonable to believe that homebuyers are aware of the water temperatures when they purchase an asset. One way water temperatures may influence prices, it is argued here, is the through providing a favorable environment for algae to bloom. The same set of instruments is, for instance, adopted by Moore et al. (2020) to address similar endogeneity concerns in the presence of algae.

The results of the 2SLS approach used to address endogeneity and measurement errors concerns through the use of a IV are presented in Table 5. Column (1) represents the results of the first stage. The results from common statistical tests used to evaluate the quality of the IV approach are also included in the table. While the instrument should display a correlation with the endogenous variable, a low correlation is often referred to as a "weak instrument problem", which results in large inconsistencies in the IV estimate (Stock, Wright and Yogo, 2002). A general rule of thumb to rule out such a possibility is to guarantee that the value of the *F*-statistic in the first stage equation is above 10 (Bound, Jaeger and Baker, 1995; Wooldridge, 2018). Such a rule is consistent with more rigorous tests too, such as the one presented in Stock and Yogo (2005). Such a condition is found to be satisfied in the first stage with the value of the *F*-statistics. The Durbin-Wu-Hausman test is also performed to evaluate the appropriateness of adopting an IV approach (Durbin, 1954; Wu, 1973; Hausman, 1978). The test is performed by comparing the estimates of the OLS and the IV approach, under the null hypothesis that the OLS approach is more efficient, i.e. has a smaller variance. In this case, the null hypothesis is reject at a p-value smaller than 0.01, suggesting that the regressor is likely endogenous, and an IV estimate should be preferred thanks to its higher efficiency. The results in Column (2) of Table 5 confirm that the presence of algae has a negative significant impact on return of investment, with each additional alga, decreasing, on average, returns on investment by 15.7%.

Table 5 Results from applying an Instrumental Variable (IV) approach

	Dependent variable:	
	Number of algae	$\Delta ln(price_{i,t,T,j})$
	1st Stage	2nd Stage
	(1)	(2)
Phosphorus	0.000	
	(0.000)	
Nitrogen	-0.00	
	(0.000)	
Water Temperature	0.067^{***}	
	(0.002)	
$\widehat{\text{Number of algae}}$		-0.157^{***}
		(0.001)
Temporal controls.	Y	Y
Postal Code F.E.	Y	Y
Asset Characteristics	Y	Y
Distance Variables	Y	Y
Observations	77,824	77,471
R^2	0.573	0.365
F-statistic:	14.1	
Note:		$^{*}p<0.1, ^{**}p<0.05, ^{***}p<0.01$

In order to showcase the independence of the results from the inclusion of the *Water Temperature* variable in the IV approach, Table A4 in the Appendix presents the results of applying the same strategy excluding this variable. The two instruments, the amount of nitrogen and the amount of phosphorus, are found to still provide a sufficiently strong instrument, albeit weaker than when the water temperature is included, and the F-statistic is well above the threshold of 10. The results from the Durbin-Hu-Hausman test confirm the superiority of the IV model and the findings of the negative impact of blooming algae on returns on investment is confirmed.

4. Discussion

By leveraging on an extensive dataset of housing transactions in Sweden and one on water quality samples investigating the presence of algae, this paper aimed at investigating the impact of blooming algae on the residential real estate prices. In doing so, it aimed to contribute to a small existing literature on the topic, and in particular to present the first assessment of such a phenomenon in Northern Europe, filling the gap identified by the previous research (Karlson *et al.*, 2022). While the results were subject to several assumptions, it is shown that these do not really play an essential role in identifying the magnitude and the direction of the impact: it is found that, on average, the return on investment on the residential market is reduced by 0.4% - 0.5% for each additional blooming algae in the closest bathing venue. The use of the repeat-sales method makes it difficult to compare these results with those produced by the previous literature, given the different nature of the dependent variable. The comparison may also be hindered by the fact that some of the previous studies focused on estimating the relationship between prices and continuous variables such as the distance from the algae (Osseni, Bareille and Dupraz, 2021), the annual occurrence of the phenomenon (Zhang, Phaneuf and Schaeffer, 2022) or the concentration in the water (Wolf and Klaiber, 2017). As far as the compatibility may be hindered, the results presented here seem in line with the previous evidence, and slightly smaller. A 43% drop in final selling prices was identified by Lamas Rodríguez et al. (2023) and such a large impact is still significantly larger than the largest estimated here with the IV approach, roughly a 15% drop for every blooming alga. The results produced by Bechard (2021) are closer to the one identified here, with the author concluding that each additional month of algae persistence reduced prices by 1%-2%. Still larger results than the ones obtained here are found in Wolf and Klaiber (2017), where a 22% price drop is imputed to the presence of the algae. One potential explanation for the significantly smaller impact observed in Sweden could be found, for instance, in the fact that the country is the largest in the European Union by share of its land surface covered by water and wetlands, with 19.1% (Eurostat, 2022). Such a large supply of water amenities may help mitigate the negative impact of the presence of algae in one body of water.

The application of the IV approach has revealed an impact that is estimated to be significantly larger than the one obtained from simply estimating the coefficient with the repeat-sales method, a common phenomenon observed in the previous literature (d'Agostino, Dunne and Pieroni, 2019; Caprettini and Voth, 2020). In some extreme cases the IV coefficient may be manyfold larger than the previous estimate that ignores endogeneity (Betz, Cook and Hollenbach, 2020). Several reasons may be found behind this result. To begin with, the IV approach was justified by the idea to address potential endogeneity concerns that may bias the results. The preference for the IV approach is not only confirmed by the Durbin-Wu-Hausman test but is also stressed by this difference. The results are substantially different because the repeat sales method alone was probably biased. Another potential explanation is that the concerns over measurement errors were well justified. As the loss of access to clean water amenities that the presence of algae introduces can be reasonably expected to impact housing prices, when this presence is not measured accurately, some assets would be recorded as not being affected when they actually are. The treated group would then be compared to a control group where the impact is assumed to be null but actually isn't, with some observations having their returns depressed by the presence of algae. When the instrument is applied, a better distinction between treated and control group can be achieved, returning a control group that can be more reasonably expected to be unaffected by the presence of algae. Another aspect to be considered relates to the fact that the IV is estimating the local average treatment effect. The phenomenon is well addressed by Card (2001). The explanation, the author argues, may be found in the heterogeneity of the marginal impact of the presence of algae on housing prices. What the IV may be estimating is the impact of the algae for those assets that suffer a marginal higher impact. The instrument affects the behavior of homeowners that are more sensible to the presence of algae. In contrast, the simple repeat-sales method is estimating the average treatment effect across the whole sample.

The evidence of the impact of algae on the returns on investment holds implications for several economic and financial actors. Beyond the health risks that the presence of these algae poses for human beings, it should be stressed that economic impacts may affect private households' finances. In a country like Sweden where 83% of the total lending to private households is composed of mortgages (SCB, 2024), the potential cascading effects for banks with large lending portfolios are relevant. The current reporting standards on financial assets require banks to set aside an adequate amount of resources as a loss provision in case of a debtor's default and with the collateral's value significantly reduced a clear impact on the banks' capitals and earnings is clear (Sveriges Riksbanken, 2018). The results should also warn policymakers against the potential fiscal implications of the presence of the algae. In a tax system where taxes are levied on the capital gain accrued from the sale of a real estate asset, such as the Swedish one (Sveriges Riksdag, 1999), the central government may incur substantial losses if these prices in the housing market are lowered by the presence of algae. The channel through which lowered housing prices may reduce tax revenues for governments has been investigated, for instance, in the context of the 2008 financial crisis (Lutz, Molloy and Shan, 2011), but should be addressed in order to motivate policymakers' incentives to tackle the effects of climate change. Lastly, discussion around the cost-efficiency to intervene to reduce the presence of blooming algae may benefit from the consideration of the societal costs that these impose through the channel of the housing market (Gallardo-Rodríguez *et al.*, 2019; Yin *et al.*, 2022).

The most recent literature on climate risks, broadly intended as the economic and financial consequences of climate change, still categorizes these into two broad groups: the consequences of natural hazards and extreme events, physical climate risks, and the consequences from shifting towards a low-carbon economy, transition climate risks (Albanese *et al.*, 2025; D'Orazio, 2025). The results presented here reveals that a phenomenon that is exacerbated by climate change, blooming algae, can have substantial negative impacts on housing markets. What is called for is a better and broader understanding that the adverse impacts of climate change cannot be constrained to the sole physical and transition climate risks.

5. Conclusions

This study has investigated the impact that the presence of blooming algae has on the Swedish residential housing market. It is found that while one single blooming alga has the potential to reduce returns on investment by as much as 5.5%, any additional alga has a very little marginal impact. The results are then assessed against the reliability of the assumptions of the repeat-sales model, mostly those of no change in the structural characteristics of the assets, and are proven to be robust. Concerns over endogeneity and measurement errors are addressed via an instrumental variable approach, which reveals even larger impacts. The possible explanation for these are discussed at length. The results could inform policymakers and lawmakers considering the implications that falling housing prices in the presence of blooming algae may have on the tax revenues of local and national governments. Scopes for further research exist and are significant: the negative impacts on economic activities from the presence of algae, including housing prices, could for instance be benchmarked against homeowners' willingness to pay to have the algae removed.

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Table A1. Full results from Table 2

	Dependent variable: $\Delta ln(price_{i,t,T,j})$	
	(1)	(2)
Living Area (m^2)	0.00151^{***}	0.00151^{***}
	(0.00005)	(0.00005)
Plot Area (m2)	0.00000^{***}	0.00000^{***}
	(0.00000)	(0.00000)
Distance bathing (m)	-0.00001^{***}	-0.00001^{***}
	(0.00000)	(0.00000)
Distance lake	-0.00001	-0.00001
	(0.00001)	(0.00000)
Distance sea	-0.00001^{***}	-0.00001^{***}
	(0.00000)	(0.00000)
W(Price)	-3.779^{***}	-3.773^{***}
	(0.0753)	(0.07525)
Number of algae	-0.00567^{***}	
	(0.00122)	
$Treatment_1$		-0.05449^{***}
		(0.00525)
$Treatment_2$		-0.05768^{***}
		(0.00887)
$Treatment_3$		-0.06375^{***}
		(0.01301)
$Treatment_4$		-0.05901^{***}
		(0.01018)
Year Control	Y	Y
Postal Code F.E.	Y	Y
Observations	77,824	77.824
R^2	0.4781	0.4789
Note:		*: p<0.1, **: p<0.05, ***: p<0.01

Table A2. Full results from Table 3

	Dependent variable: $\Delta ln(price_{i,t,T,j})$	
	(1)	(2)
Living Area (m^2)	0.00151^{***}	0.0015^{***}
	(0.00005)	(0.00005)
Renovated	0.02516^{***}	0.25330^{***}
	(0.07602)	(0.07596)
Plot Area (m^2)	0.00000***	0.00000^{***}
	(0.00000)	(0.00000)
Distance bathing (m)	-0.00001^{***}	-0.00001^{***}
	(0.00000)	(0.00000)
Distance lake	-0.00001	-0.00001
	(0.00001)	(0.00001)
Distance sea	-0.00001^{***}	-0.00001^{***}
	(0.00000)	(0.00000)
W(Price)	-3.779^{***}	-3.773^{***}
	(0.0753)	(0.07524)
Number of algae	-0.00566^{***}	
	(0.00122)	
$Treatment_1$		-0.05442^{***}
		(0.00525)
$Treatment_2$		-0.05789^{***}

		(0.00887)
Treatment₃		***-0.06383******
		(0.01301)
Treatment₄		***-0.05889******
		(0.01018)
Year Control	***Y***	***Y***
Postal Code F.E.	***Y***	***Y***
Observations	***77,824***	***77.824***
R^2	***0.4782***	***0.479***
Note:		*: $p<0.1$, **: $p<0.05$, ***: $p<0.01$

Table A3 Full results from Table 4

	Dependent variable:	
	$\Delta ln(price_{i,t,T,j})$	
	(1)	***(2)***
Living Area (m^2)	***0.00141******	***0.00141******
	(0.00005)	*(0.00005)*
Plot Area (m2)	***0.00000******	***0.00000******
	(0.00000)	*(0.00000)*
Distance bathing (m)	***-0.00001******	***-0.00001******
	(0.00000)	*(0.00000)*
Distance lake	***-0.00009***	***-0.00001***
	(0.00001)	*(0.00000)*
Distance sea	***-0.00001******	***-0.00001******
	(0.00000)	*(0.00000)*
W(Price)	***-3.974******	***-3.965******
	(0.08263)	*(0.08256)*
Number of algae	***-0.00442******	
	(0.0013)	
Treatment₁		***-0.05762******
		(0.00547)
Treatment₂		***-0.04951******
		(0.0092)
Treatment₃		***-0.0555******
		(0.01342)
Treatment₄		***-0.04383******
		(0.01083)
Year Control	***Y***	***Y***
Postal Code F.E.	***Y***	***Y***
Observations	***66,815***	***66,815***
R^2	***0.4628***	***0.4638***
Note:		$^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$

Table A4 Full results from Table 5

	Dependent variable:	
	Number of algae	$\Delta ln(price_{i,t,T,j})$
	(1)	***(2)***
Living Area (m^2)	***0.00015***	***0.0015******
	(0.00015)	*(0.00006)*
Plot Area (m^2)	***0.00000***	***0.00000******
	(0.00000)	*(0.00000)*
Distance bathing (m)	***-0.00000***	***-0.00001******
	(0.00000)	*(0.00000)*
Distance lake	***-0.00002***	***-0.00000***
	(0.00001)	*(0.00000)*
Distance sea	***0.00002******	***-0.00001******
	(0.00000)	*(0.00000)*

W(Price)	***0.6379*******	***-3.6594*******
	(0.2281)	***(0.08303)***
Total phosphorus	***-0.00000***	
	(0.00000)	
Total nitrogen	***0.00000***	
	(0.00000)	
Number of warm water days	***0.06717*******	
	(0.0015)	
$\widehat{\text{Number of}}$ algae		***-0.15692*******
		(0.00135)
Year Control	***Y***	***Y***
Postal Code F.E.	***Y***	***Y***
Observations	***77,824***	***77,824***
R^2	***0.5773***	***0.3565***
Note:		****p<0.1,**p<0.05,***p<0.01***

Table A5 Assessing the robustness of the IV approach against the inclusion of the "Number of warm water days" variable

	Dependent variable:	
	Number of algae	$\Delta ln\left(price_{i,t,T,j}\right)$
	(1)	***(2)***
Living Area (m^2)	***-0.00021***	***0.00135*******
	(0.00015)	***(0.00012)***
Plot Area (m^2)	***0.00000***	***0.00000***
	(0.00000)	***(0.00000)***
Distance bathing (m)	***0.00000***	***-0.00001*******
	(0.00000)	***(0.00000)***
Distance lake	***0.00003****	***0.00002***
	(0.00002)	***(0.00001)***
Distance sea	***0.00003******	***0.00000***
	(0.00000)	***(0.00000)***
W(Price)	***0.7934******	***-3.1915***
	(0.2312)	
Total phosphorus	***-0.00000***	
	(0.00000)	
Total nitrogen	***0.00000***	
	(0.00000)	
$\widehat{\text{Number of}}$ algae		***-0.74716******
		(0.00304)
Year Control	***Y***	***Y***
Postal Code F.E.	***Y***	***Y***
Observations	***77,824***	***77,824***
F-statistic	***13.43***	
R^2	***0.5653***	
Note:		****p<0.1,**p<0.05,***p<0.01***