water

MDPI

Article

Revealing Public Perceptions of Biodiverse vs. Turf Swales: Balancing Enhanced Ecosystem Services with Heightened Concerns

Hong Wu [1,*], Margaret C. Hoffman [2], Rui Wang [3], Kathleen M. Kelley [2] and Mahsa Adib [1]

[1] Department of Landscape Architecture, The Pennsylvania State University, University Park, PA 16801, USA; mva5844@psu.edu
[2] Department of Plant Science, The Pennsylvania State University, University Park, PA 16801, USA; mch7@psu.edu (M.C.H.); kmk17@psu.edu (K.M.K.)
[3] School of Art and Design, Wuhan University of Technology, Wuhan 430070, China; ruiwang1012@whut.edu.cn
* Correspondence: huw24@psu.edu; Tel.: +1-814-863-5284

Abstract: Green stormwater infrastructure (GSI) is increasingly implemented worldwide to address stormwater issues while providing co-benefits such as habitat provision. However, research on public perceptions of GSI's ecosystem benefits is limited, and barriers such as perception and maintenance hinder biodiversity promotion in GSI. Through an online survey (n = 781), we explored how residents in four Northeast US urban areas—Prince George's County and Montgomery County, MD, New York City, and Philadelphia, PA—perceived the benefits and concerns regarding two types of bioswales (biodiverse and turf). Biodiverse swales feature various plants to promote biodiversity, whereas turf swales are primarily grass-covered. Our analyses included paired-samples t-tests, independent t-tests, one-way repeated measures ANOVA tests, and one-way ANOVA tests to compare perceptions across bioswale types, aspects of benefit/concern, and locations. Both bioswale types were recognized for enhancing green spaces and neighborhood aesthetics. Residents perceived greater environmental and social benefits from biodiverse swales than turf swales, particularly for habitat provision. While overall concerns for both bioswale types were low, potential issues like pest cultivation and the unappealing appearance of biodiverse swales remain significant barriers. Notably, implementing biodiverse swales alleviated initial concerns, especially about pests, suggesting familiarity can enhance acceptance. Location-specific differences in perception were observed, with New York City showing higher perceived benefits and concerns and Montgomery County exhibiting the lowest concerns. This variance is likely due to distinct urban environments, levels of environmental awareness, and demographic profiles.

Keywords: biodiverse swales; turf swales; ecosystem benefit; concern; green stormwater infrastructure; public perception

check for updates

Citation: Wu, H.; Hoffman, M.C.; Wang, R.; Kelley, K.M.; Adib, M. Revealing Public Perceptions of Biodiverse vs. Turf Swales: Balancing Enhanced Ecosystem Services with Heightened Concerns. *Water* **2024**, *16*, 2899. https://doi.org/10.3390/w16202899

Academic Editor: Richard Smardon

Received: 4 September 2024
Revised: 4 October 2024
Accepted: 11 October 2024
Published: 12 October 2024

1. Introduction

Flooding and water quality challenges associated with climate change, urbanization, and aging infrastructure have become a global concern [1]. Green stormwater infrastructure (GSI), defined as stormwater management practices (e.g., rain gardens and bioswales) mimicking natural ecohydrological processes, has gained popularity worldwide in the past two decades as a key strategy to restore the hydrological cycle and address flooding and water quality issues [2].

One of the leading challenges of implementing GSI is achieving multiple co-benefits beyond the stormwater reduction and water quality treatment goals [3–5]. There is growing acknowledgment that GSI yields a wide array of added ecosystem benefits. These include environmental benefits (e.g., climate change mitigation, increased biodiversity), social benefits (e.g., aesthetic enhancement, environmental education, and health value), and economic benefits (e.g., property value increase) [5–8]. However, these co-benefits tend to be overlooked during the design and implementation processes due to a lack of interdisciplinary coordination [9], as well as the scarcity of evidence regarding both the monitored and perceived co-benefits [4].

Because we are in the midst of a global biodiversity catastrophe, there is an urgent need to enhance GSI implementation to bolster urban ecosystem health and promote biodiversity [9,10]. Protecting diminishing natural lands is simply no longer enough in a world so dramatically altered by land development [11,12]. It is imperative to rebuild ecological diversity and abundance within the cities, particularly through green infrastructure development, to sustain ecological functions for future generations [13]. Furthermore, there is growing evidence that biodiversity enhances other ecosystem functions [14] and can improve the performance and resilience of GSI [15,16]. For instance, increasing plant species diversity can create more heterogeneous root structures, thereby increasing water absorption and improving water quality [17].

However, there are significant obstacles, such as those related to public perception and maintenance, to promoting biodiversity in GSI [18–20]. The public commonly prefers "neat" landscapes, such as turf-based GSI, over biodiverse ones with a variety of plant species. The latter are often perceived as unkempt and messy, especially in the absence of adequate maintenance, challenging the established sociocultural norm for what a cared-for street landscape should look like [21]. Additionally, other concerns, such as fear of insects, further complicate acceptance of biodiverse designs [22,23].

Due to these obstacles, it is essential to collect residents' input to better understand the public concerns regarding the potential adverse effects of biodiverse GSI compared to those designed with little biodiversity considerations. The literature has documented a variety of concerns about GSI in general, encompassing issues related to design, construction, functionality, appearance, maintenance, economic feasibility, and social equity. People worry about safety, poor design, defective construction, undesirable placement, and lack of maintenance [20,24–27], in addition to high initial cost and balancing that with long-term environmental benefits [3,26,28]. Some homeowners in Australia, Canada, and the USA also worry that green infrastructure would lower home values [29–31]. Inequitable GSI implementation in vulnerable communities has also raised social equity concerns [28]. However, most of these studies solicited stakeholder perspectives of public concerns through interviews [3], lacking quantitative assessments of direct public input, such as the prevalence and intensity of listed concerns.

Furthermore, residents' perceived and experienced concerns may vary across GSI types and geographic contexts [20], yet existing studies often consider GSI as an overarching term [3,20] instead of delving into specific types. Comparative studies across different regions are also scarce. This lack of granularity limits our understanding of how residents in different areas perceive various types of GSI, hindering targeted interventions and effective communication strategies.

To improve GSI's co-benefit provision, we must also understand the extent to which the public perceives those multifaceted benefits [4,7,32]. Research indicates that public opinions on environmental initiatives are shaped not only by individual knowledge of ecological impacts but also by broader social and psychological factors, including perceptions of community benefits, personal responsibility, and the long-term sustainability of these initiatives [33,34]. For instance, individuals are more likely to support GSI projects when they believe such projects will lead to tangible improvements in their local environment [35]. Understanding which ecosystem benefits are crucial to residents can inform the design of effective, community-supported GSI projects [36]. Such knowledge also allows managers to navigate the synergies and trade-offs among co-benefits, optimize GSI planning and design, and identify public education and outreach opportunities [37,38].

Similar to the gap in understanding perceived concerns, there is a notable lack of fine-grained insights into the perceived ecosystem benefits of specific GSI types across different geographical contexts. Most studies relied on inputs from professionals or experts instead of directly from the public [39]. Emerging empirical studies tend to assess GSI as a whole [7,8,40–45]. Only a few have delved into the nuanced differences across GSI types. For example, Elliot et al. (2020) [39] assessed the ability of 14 types of green infrastructure to provide 22 ecosystem services (ESs) in New York City, drawing on the opinions of 46 academic experts. They found that parks, wetlands, and community gardens were more strongly positively related to ES provision than other green infrastructure types. Common public right-of-way GSI, such as bioswales and green streets, were only highly linked to water quality mitigation. However, their connections to the other 21 ESs were moderate (14 ESs), low (4 ESs), or negative (3 ESs). Choi et al. (2021) [8] reviewed the climate benefits and co-benefits of 24 types of green infrastructure, reporting similarly stronger evidence for the effectiveness of bioswales and bioretention/rain gardens in managing floods and improving water quality compared to other benefits. Lastly, Miller and Montalto [4] explored the perception of 20 types of ESs provided by six GSI types (i.e., bioswales, green roofs, street trees, community gardens, parks and natural areas, and permeable playgrounds) by four stakeholder groups with varying levels of GSI familiarity in New York City. They found that bioswales, for example, were rated by the residents and practitioners as the third-best GSI type for providing ESs, following parks and natural areas and community gardens. However, residents' collective perception of ESs from bioswales and the comparisons across different ESs were not reported because the results were presented separately by stakeholder groups. This limits our understanding of which specific ESs were the most recognized by the residents.

Finally, when measuring public perceptions of benefits and concerns, it is necessary to distinguish between *actual* and *assumed* perceptions, an aspect rarely explored in the literature. We define actual perceptions as held by residents with GSI installed on their streets, while assumed perceptions are held by those without such installations. Contrasting these two conditions will help identify whether previous implementation leads to greater familiarity and influence perceptions.

To address the literature gaps mentioned above, this study focuses on a specific type of GSI, the widely implemented bioswales (e.g., in the public right-of-way), to better understand the public's perceived ecosystem benefits and concerns. Here, bioswales are defined as vegetated, shallow, landscaped depressions designed to capture, treat, and infiltrate stormwater runoff [46]. In particular, we explore the differences in perceptions between two variations of bioswales, i.e., biodiverse and turf bioswales, to uncover the barriers to promoting biodiversity in GSI and inform strategies to overcome them. Biodiverse swales feature a variety of plant materials (e.g., perennials, monocots, and woody plants) to promote biodiversity, whereas turf swales are predominantly covered with turf grass. Additionally, we investigate whether geographical locations impact public perceptions by conducting the study across four municipal areas: New York City, NY (NYC); Philadelphia, PA (Philly); Montgomery County, MD (MoCo); and Prince George's County, MD (PG). We specifically address the following research questions:

1. What ecosystem benefits do the public perceive from biodiverse and turf swales? How do levels of perception differ between the two types of bioswales?
2. What concerns do the public have about biodiverse and turf swales, and how do they compare?
3. How do the four municipal areas compare to each other in terms of concerns and benefit perception?
4. Does the implementation of bioswales influence people's perception of benefits and concerns?

2. Materials and Methods

2.1. Research Design and Sampling Protocols

An internet survey was administered in July 2022 by Dynata (https://www.dynata.com/; accessed on 15 July 2022), a major first-party data platform that helps collect responses from its large panelist base [47]. Panelists were compensated by Dynata's internal scheme to encourage participation. Adult participants over 21 years old were recruited from the four locations mentioned above: NYC, Philly, MoCo, and PG. These four areas were selected due to their widespread GSI implementation. Implied consent was obtained on the first screen before consenting participants were directed to the survey housed on Qualtrics.com. The study design and survey instrument (see Section S1, Supplementary Materials) were reviewed and deemed exempt by the Pennsylvania State University's Institutional Review Board (STUDY00020550).

The survey instrument was in plain language. It was pilot-tested on a subset (n = 100) of the target panelist base and revised before distribution. It consisted of 18 questions about the participants' residing location, whether they had either type of bioswales installed on their streets, ratings of perceived environmental, social, and economic ecosystem benefits (measured on a 7-point Likert scale) and concerns (measured on a 5-point Likert scale) for biodiverse vs. turf swales, the top three ecosystem benefits most important to the participants, and demographic information (Section S1). Thirteen ecosystem benefits and eight concerns were selected from existing literature based on their relevance to bioswales. The benefits included four environmental benefits (i.e., flood mitigation, Urban Heat Island (UHI) mitigation, habitat value, and water quality improvement); eight social benefits (i.e., green space provision, enhanced neighborhood aesthetics and vitality, noise reduction, health, recreation, raising water environment awareness, and promoting reflection on the people–water relationship), and one economic benefit (i.e., increased home value). Participants also described additional benefits they perceived as important if these were different or not included in the list of the 13 provided. The concerns included the potential to harbor pests, unappealing appearance, health concerns about pollutants, inadequacy in treating stormwater, maintenance burden, children's safety, loss of parking, and decreased home value.

2.2. Data Analysis

A total of 2049 panelists attempted the finalized survey, 1862 qualified, and 1500 responded to at least one survey question. Further data screening excluded responses completed under five minutes and those containing identical responses for the same section or meaningless entries for open-ended questions. This resulted in 781 completed surveys used in the subsequent data analysis. All data were analyzed using SPSS version 27.

First, descriptive statistics of participant profiles and perceived benefits and concerns were generated. Then, the samples were partitioned in different ways for group comparisons. Specifically, biodiverse and turf swales were compared using paired-samples t-tests to identify which bioswale type delivered stronger benefits or incurred higher concerns. Within each bioswale type, the multiple aspects of benefits and concerns were compared using one-way repeated measures ANOVA tests to generate rankings of benefits and concerns. When the ANOVA test result was significant ($p < 0.05$), post-hoc pairwise tests using Tukey HSD were conducted to identify which specific pairs differed. Moreover, participants were divided into two groups: those with biodiverse or turf swales installed on their streets vs. those without. This way, actual perceived benefits or concerns (the former group) were compared with assumed benefits or concerns (the latter group) using independent t-tests to identify if bioswale implementation changed perceptions. Finally, the four study locations were compared using one-way ANOVA tests to identify city/county differences in perceived benefits and concerns. When the ANOVA test result was significant ($p < 0.05$), post-hoc pairwise tests were conducted to identify which specific pairs of municipal areas differed.

3. Results

3.1. Sample Characteristics

The 781 complete responses showed a relatively balanced distribution among the four areas (Table 1). Slightly over half of the respondents were female (54%). The average

age was around 48 years old. Sixty-one percent of the respondents held a bachelor's or higher degree. About 42% had their 2021 household income exceeding USD 100,000. More participants had turf (n = 317) swales than biodiverse (n = 251) swales installed in their neighborhoods. Regarding city/county differences (see detailed statistics in Table S1, Section S2, Supplementary Materials), NYC had significantly more male participants than the other three locations; there were no age differences among the four locations; NYC and MoCo participants were more educated and had higher incomes than Philly and PG.

Table 1. Participants' demographic profiles.

	City/County				Total %	Total N
	Philadelphia, PA	New York City, NY	Montgomery County, MD	Prince George's County, MD		
Sample size	244	228	178	131	100%	781
Gender						
Male	35%	64%	42%	34%	45%	350
Female	64%	36%	58%	65%	54%	425
Age						
21–33	14%	15%	16%	19%	16%	122
34–57	60%	58%	57%	50%	57%	444
58–67	18%	15%	19%	20%	17%	136
≥68	8%	13%	8%	12%	10%	79
Education level						
High school/GED or below	20%	13%	7%	23%	15%	119
Technical/vocational	8%	3%	0%	5%	4%	32
Some college	25%	12%	16%	24%	19%	151
Bachelor's	26%	29%	37%	24%	29%	226
Master's and Ph.D.	21%	44%	40%	24%	32%	253
Household income (2021)						
<USD 49,999	43%	19%	12%	28%	27%	208
USD 50,000–99,999	29%	25%	21%	30%	26%	204
USD 100,000–149,999	16%	21%	28%	24%	21%	166
≥USD 150,000	6%	31%	33%	13%	21%	160

3.2. Perceived Benefits of Biodiverse and Turf Swales

The respondents assessed how strongly they had perceived 13 types of ecosystem benefits provided by biodiverse and turf swales. On average, overall ecosystem benefit (EB) perception (mean of 13 benefits) fell around "somewhat perceived" for biodiverse swales (Avg_EB_Biodiverse mean = 4.93 on a 7-point scale) and between "neutral" and "somewhat perceived" for turf swales (Avg_EB_Turf mean = 4.67) (Table 2). The overall benefit perception from biodiverse swales significantly exceeded that from turf swales. Moreover, the participants showed significantly stronger perceptions of both environmental and social benefits from biodiverse than turf swales. Economic benefit perception was the same between the two bioswale types.

For biodiverse swales, the perception of their environmental benefits (Avg_EnB_Biodiverse mean = 5.16) was significantly stronger than their social benefits (Avg_SoB_Biodiverse mean = 4.82) ($t(777) = 9.626$, $p < 0.001$, $d = 0.345$). For turf swales, the perception of their environmental benefits (Avg_EnB_Turf mean = 4.59) was slightly but significantly weaker than their social benefits (Avg_SoB_Turf mean = 4.68) ($t(777) = -2.795$, $p = 0.005$, $d = -0.100$).

Regarding the ranking of individual environmental benefits, the one-way repeated measures ANOVA and post-hoc tests revealed significant group and pairwise differences for both biodiverse and turf swales ($F(2.894, 2240.223) = 75.824$, $p < 0.001$ for biodiverse swales; $F(2.771, 2128.205) = 42.036$, $p < 0.001$ for turf swales) (Figure 1). For biodiverse swales, the strongest perceived environmental benefit was attracting wildlife, while the weakest was UHI mitigation (Table S2, Section S2). In contrast, for turf swales, participants perceived significantly stronger benefits of flood mitigation and water quality improvement than UHI mitigation and habitat provision (Table S2, Section S2).

Table 2. Comparisons of means of perceived benefits of biodiverse and turf swales.

Benefit	Bioswale Type	N	Level of Perception Mean	S.D.	*t*-Test Statistics
Average of 13 benefits *	Biodiverse Turf	779 778	4.93 4.67	1.05 1.09	t(778) = 7.857, $p < 0.001$; $d = 0.282$
Average of environmental benefits *	Biodiverse Turf	778 778	5.16 4.59	1.09 1.22	t(776) = 13.163, $p < 0.001$; $d = 0.472$
Average of social benefits *	Biodiverse Turf	779 778	4.82 4.68	1.18 1.17	t(777) = 3.695, $p < 0.001$; $d = 0.132$
Economic benefit	Biodiverse Turf	780 777	4.89 4.84	1.48 1.42	t(773) = 1.032, $p = 0.302$; d = 0.037

Note: * indicates the presence of a statistically significant difference between the two bioswale types.

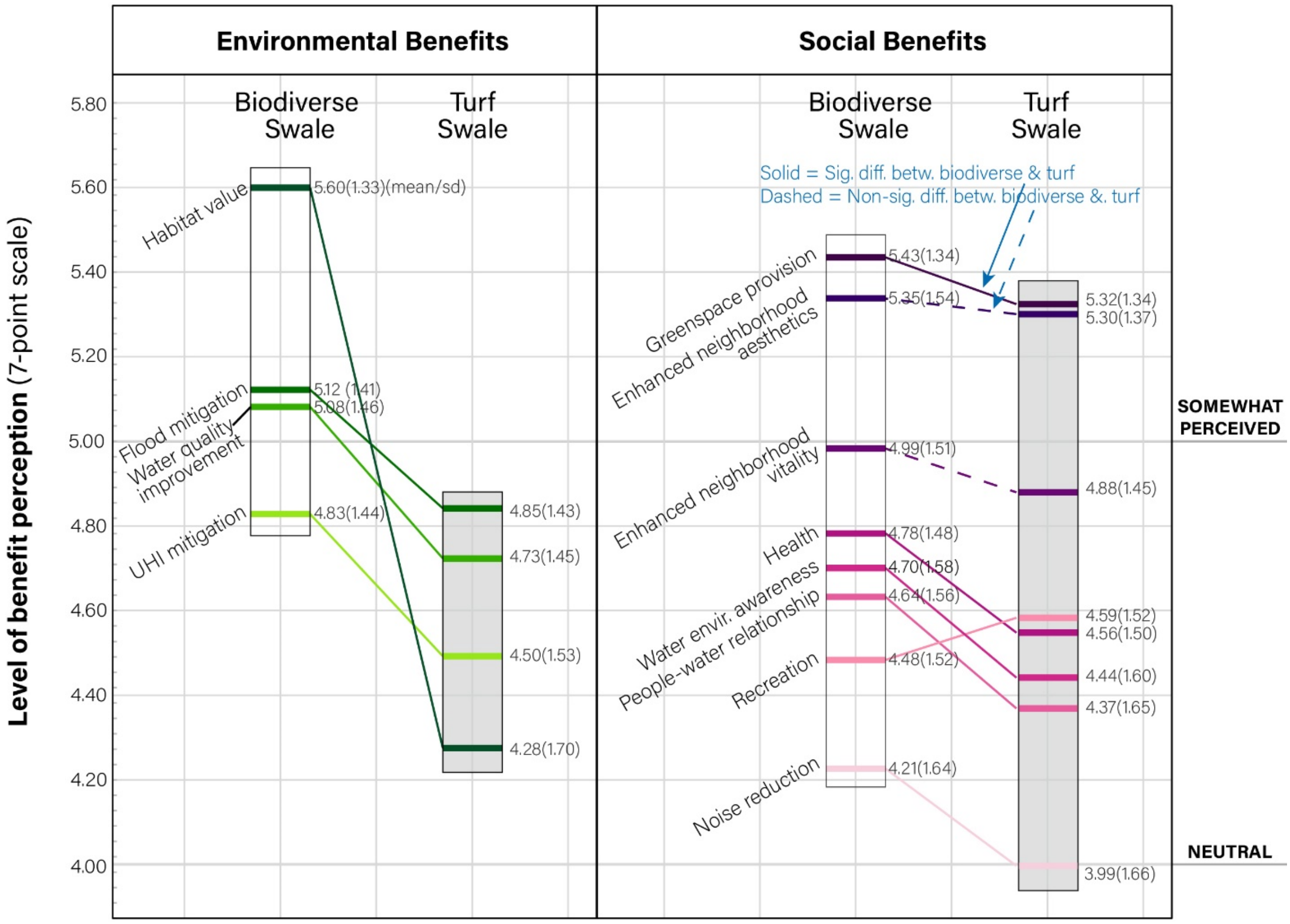

Figure 1. Comparisons of perceived environmental and social benefits of biodiverse and turf swales. #.##(#.##) represents the mean (standard deviation) of each perceived benefit for either biodiverse or turf swales. The solid lines indicate statistically significant differences between biodiverse and turf swales, while the dashed lines indicate non-significant differences.

Similarly, regarding the ranking of individual social benefits, the one-way repeated measures ANOVA and post-hoc tests revealed significant group and pairwise differences for both biodiverse and turf swales ($F(5.507, 4196.578) = 125.263$, $p < 0.001$ for biodiverse swales; $F(5.072, 3880.043) = 158.927$, $p < 0.001$ for turf swales) (Figure 1). The strongest social benefits were the same for biodiverse and turf swales, including greenspace provision and enhanced neighborhood aesthetics. However, the weakest benefits slightly differed. Participants consistently ranked water relationships and noise reduction as the lowest benefits for both bioswale types. Biodiverse swales were also considered to provide little recreational value, and turf swales were considered to contribute little to raising water environment awareness (Figure 1 and Table S3, Section S2).

When the 13 individual benefits were compared within each bioswale type, habitat, greenspace provision, and enhanced neighborhood aesthetics were the three strongest for biodiverse swales, whereas noise reduction, recreation, and prompting reflection on water relationships ranked at the bottom (Figure 1 and Table S4, Section S2). For turf swales, greenspace provision and enhanced neighborhood aesthetics were the strongest, whereas noise reduction, habitat, and prompting reflection on water relationships ranked among the lowest (Figure 1 and Table S4, Section S2).

When the two bioswale types were compared for individual benefits, 10 out of 13 measures showed significant differences (see solid lines in Figure 1), except for enhanced neighborhood aesthetics, vitality, and increased property value. In 9 of these 10 cases, biodiverse swales were perceived to provide more substantial benefits than turf swales, with recreation value being the only exception where turf swales offer higher benefits (Table S5, Section S2).

When the benefit perceptions of people with biodiverse swales installed on their streets (i.e., the actual benefits) were compared with those without (i.e., the assumed benefits), 5 out of 13 benefit measures showed significant differences (Table 3). For four aspects—flood mitigation, water quality improvement, enhanced neighborhood vitality, and health—actual benefits were lower than assumed benefits. In other words, implementation lowered benefit perception under these circumstances. In contrast, for raising water environment awareness, the actual benefit exceeded the assumed benefit. Effect size (Cohen's *d*) ranged from 0.205 to 0.489. The difference in benefit perception was the most pronounced for water quality improvement (d = 0.489).

Table 3. Comparisons of actual vs. perceived benefits from biodiverse and turf swales.

Benefits	Group	Biodiverse Swales			Turf Swales		
		N	Mean	S.D.	N	Mean	S.D.
Flood mitigation	Actual	251	**4.82** *	1.40	317	4.93	1.40
	Assumed	529	**5.26**	1.39	462	4.79	1.45
	t-test statistics	t(778) = 4.081, $p < 0.001$, $d = 0.313$			t(777) = −1.298, $p = 0.195$		
UHI mitigation	Actual	250	4.75	1.52	314	***4.75*** †	1.57
	Assumed	528	4.87	1.40	462	***4.33***	1.48
	t-test statistics	t(776) = 1.114, $p = 0.226$			t(646.622) = −3.715, $p < 0.001$, $d = -0.275$		
Habitat value	Actual	250	5.66	1.26	316	4.40	1.83
	Assumed	526	5.57	1.36	460	4.20	1.61
	t-test statistics	t(774) = −0.878, $p = 0.380$			t(618.501) = −1.620, $p = 0.106$		
Water quality improvement	Actual	249	**4.61**	1.56	314	4.81	1.51
	Assumed	528	**5.31**	1.35	460	4.68	1.41
	t-test statistics	t(429.142) = 6.046, $p < 0.001$, $d = 0.489$			t(772) = −1.278, $p = 0.201$		
Greenspace provision	Actual	251	5.42	1.40	314	***5.51***	1.26
	Assumed	529	5.44	1.31	464	***5.20***	1.38
	t-test statistics	t(778) = 0.197, $p = 0.844$			t(776) = −3.196, $p = 0.001$, $d = -0.234$		

Table 3. *Cont.*

Benefits	Group	Biodiverse Swales			Turf Swales		
		N	Mean	S.D.	N	Mean	S.D.
Enhanced neighborhood aesthetics	Actual	248	5.29	1.57	315	5.38	1.33
	Assumed	527	5.38	1.53	462	5.25	1.40
	t-test statistics	t(773) = 0. 720, *p* = 0.472			t(775) = −1.349, *p* = 0.178		
Promotion of water environment awareness	Actual	249	***4.94***	1.57	314	***4.81***	1.63
	Assumed	527	***4.58***	1.57	461	***4.18***	1.52
	t-test statistics	t(774) = −2.960, *p* = 0.003, *d* = −0.228			t(642.951) = −5.429, *p* < 0.001, *d* = −0.402		
Noise reduction	Actual	248	4.05	1.71	315	***4.23***	1.77
	Assumed	521	4.29	1.60	459	***3.82***	1.55
	t-test statistics	t(767) = 1.864, *p* = 0.063			t(615.180) = −3.322, *p* = 0.001, *d* = −0.249		
Enhanced neighborhood vitality	Actual	249	**4.65**	1.59	316	4.89	1.50
	Assumed	527	**5.15**	1.45	461	4.88	1.42
	t-test statistics	t(448.614) = 4.167, *p* < 0.001, *d* = 0.331			t(775) = −0.121, *p* = 0.903		
Recreation value	Actual	250	4.53	1.56	316	***4.78***	1.58
	Assumed	526	4.45	1.50	462	***4.45***	1.47
	t-test statistics	t(774) = −0.662, *p* = 0.508			t(642.693) = −2.933, *p* = 0.003, *d* = −0.217		
Health value	Actual	250	**4.57**	1.59	316	4.67	1.63
	Assumed	528	**4.88**	1.42	462	4.48	1.40
	t-test statistics	t(443.272) = 2.571, *p* = 0.010, *d* = 0.205			t(607.645) = −1.688, *p* = 0.092		
Promotion of reflection on people–water relationship	Actual	250	4.73	1.62	316	***4.81***	1.67
	Assumed	527	4.59	1.54	459	***4.07***	1.56
	t-test statistics	t(775) = −1.181, *p* = 0.238			t(648.295) = −6.282, *p* < 0.001, *d* = −0.465		
Increased property value	Actual	250	4.77	1.55	316	***5.00***	1.45
	Assumed	527	4.95	1.43	461	***4.74***	1.40
	t-test statistics	t(453.424) = 1.568, *p* = 0.117			t(775) = −2.521, *p* = 0.012, *d* = −0.184		

Notes: * Bold underlined means indicate actual benefit was significantly lower than assumed benefit; † Italic, bold underlined means indicate actual benefit was significantly higher than assumed benefit.

For turf swales, 7 out of 13 benefits showed significant differences between actual and assumed benefits, including UHI mitigation, greenspace provision, raising water environment awareness, noise reduction, recreation, promoting reflection on water relationship, and increased property value (Table 3). In all these cases, the actual benefits exceeded the assumed benefits. In other words, implementation increased benefit perception under these circumstances. Effect size (Cohen's *d*) ranged from 0.184 to 0.465. The difference in benefit perception was the most pronounced for promoting reflection on water relationships (*d* = 0.465).

Finally, the top two, of three, ecosystem benefits most important to the participants for both biodiverse and turf swales were flood mitigation and water quality improvement. The third benefit differed with habitat value being important for biodiverse swales and enhanced neighborhood aesthetics for turf swales. Additionally, besides the 13 benefits listed, participants also indicated that they perceived increased job opportunities, air quality improvement, and carbon sequestration from both types of bioswales, as well as erosion reduction, increased access to nature, reduced mowing costs and pollution, and seed dispersion or collection from biodiverse swales.

3.3. Concerns about Turf and Biodiverse Swales

For both types of bioswales, the average concern levels of all eight effects were from slight to moderate (means ranged from 2.59 to 3.26 for biodiverse and 2.46 to 2.89 for turf swales) (Figure 2). The aggregated means of concern over biodiverse (2.86) and turf swales (2.71) both fell mildly below "moderately concerned." The paired-samples t-test showed that the average concern on biodiverse swales was significantly higher than on turf swales (t(780) = 5.865, $p < 0.001$, $d = 0.210$).

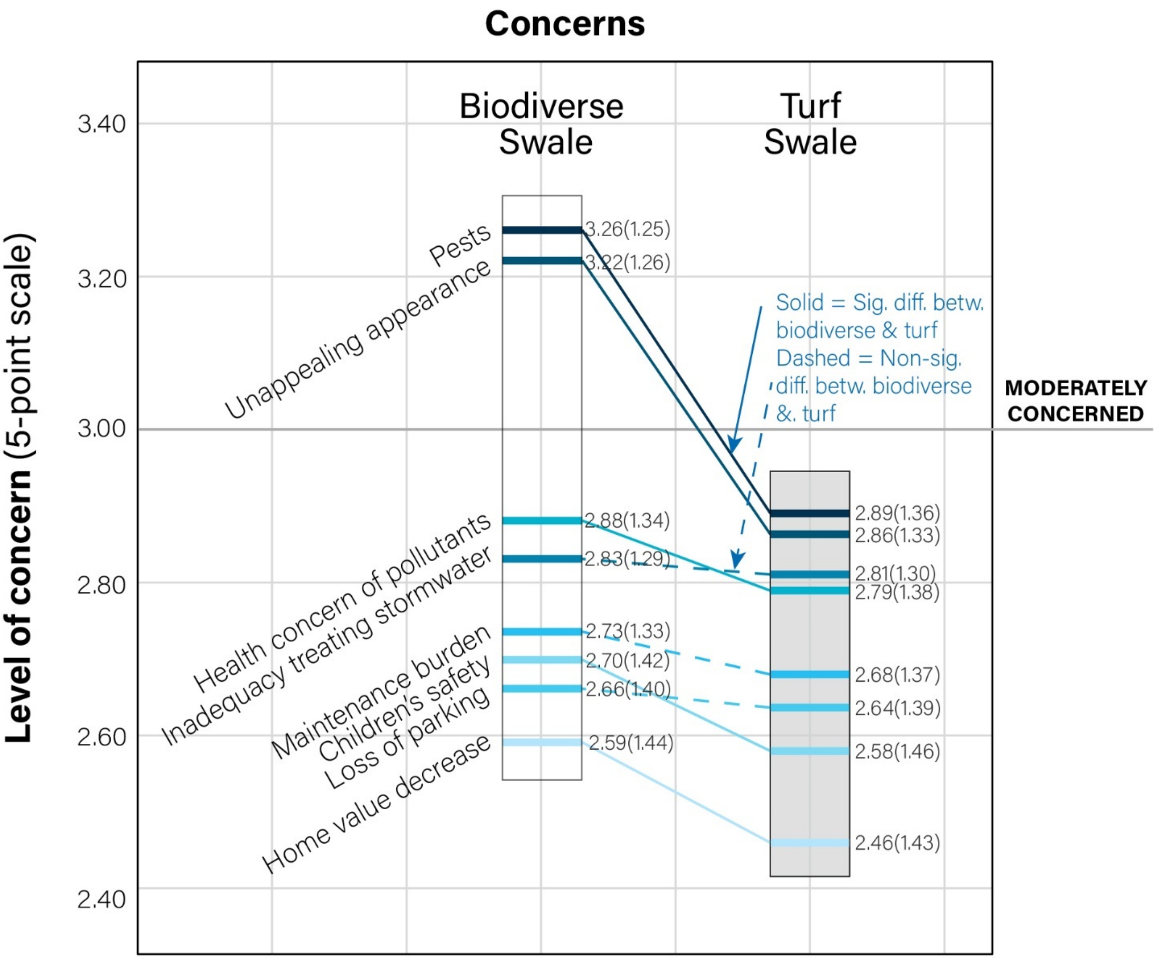

Figure 2. Comparison of concerns over biodiverse and turf swales. #.##(#.##) represents the mean (standard deviation) of each perceived concern for either biodiverse or turf swales. The solid lines indicate statistically significant differences between biodiverse and turf swales, while the dashed lines indicate non-significant differences.

Regarding the rankings of individual concerns, the one-way repeated measures ANOVA and post-hoc tests revealed significant group and pairwise differences for both biodiverse and turf swales (F(6.137, 4578.158) = 60.239, $p < 0.001$ for biodiverse swales; F(6.247, 4666.313) = 26.450, $p < 0.001$ for turf swales). The highest and lowest concerns were identical for both bioswale types (Figure 2). Participants were the most concerned about bioswales potentially harboring pests and appearing wild/weedy and unappealing but the least about adverse effects on home value (Table S6, Section S2).

When the two bioswale types were compared for individual concerns, 5 out of 8 measures showed significant differences (see solid lines in Figure 2), including pests, unappealing appearances, health concerns about pollutants, children's safety, and home value decrease. For these aspects, concerns on biodiverse swales exceeded those on turf swales (Table S7, Section S2).

Interestingly, for 6 out of 8 potential adverse effects (except for home value decrease and loss of parking with no significant differences), people with biodiverse swales installed on their streets (i.e., actual concern) showed significantly lower concerns than those without (i.e., assumed concern) (Table 4). In other words, implementation reduced concern under these circumstances. Effect size (Cohen's *d*) ranged from 0.285 to 0.390. The difference in concern levels was the most pronounced for "potentially harbor mosquitos/other pests" (*d* = 0.390).

Table 4. Comparisons of actual vs. assumed concerns over biodiverse and turf swales.

Concern	Group	Biodiverse Swales			Turf Swales		
		N	Mean	S.D.	N	Mean	S.D.
Pests	Actual	249	**2.93** *	1.295	316	2.97	1.400
	Assumed	525	**3.41**	1.205	459	2.83	1.326
	t-test statistics	t(772) = 5.069, $p < 0.001$, $d = 0.390$			t(773) = −1.395, $p = 0.164$, $d = -0.102$		
Unappealing appearance	Actual	248	**3.02**	1.316	315	2.95	1.360
	Assumed	525	**3.31**	1.225	458	2.80	1.310
	t-test statistics	t(771) = 3.063, $p = 0.002$, $d = 0.236$			t(771) = −1.496, $p = 0.135$, $d = -0.109$		
Health concerns about pollutants	Actual	250	**2.68**	1.303	315	***2.91*** †	1.429
	Assumed	522	**2.98**	1.342	458	***2.71***	1.343
	t-test statistics	t(770) = 2.999, $p = 0.003$, $d = 0.231$			t(771) = −1.975, $p = 0.049$, $d = -0.145$		
Inadequacy treating stormwater	Actual	249	**2.69**	1.300	314	2.91	1.342
	Assumed	519	**2.90**	1.278	456	2.74	1.270
	t-test statistics	t(766) = 2.091, $p = 0.037$, $d = 0.161$			t(768) = −1.780, $p = 0.076$, $d = -0.131$		
Maintenance burden	Actual	251	**2.48**	1.369	316	2.76	1.486
	Assumed	527	**2.84**	1.290	461	2.62	1.279
	t-test statistics	t(466.450) = 3.554, $p < 0.001$, $d = 0.278$			t(608.811) = −1.386, $p = 0.166$, $d = -0.104$		
Children's safety	Actual	248	**2.48**	1.365	315	***2.77***	1.518
	Assumed	518	**2.81**	1.429	456	***2.45***	1.399
	t-test statistics	t(764) = 2.990, $p = 0.003$, $d = 0.231$			t(638.859) = −3.008, $p = 0.003$, $d = -0.224$		
Loss of parking	Actual	248	2.54	1.390	310	2.72	1.414
	Assumed	521	2.72	1.401	458	2.58	1.370
	t-test statistics	t(767) = 1.627, $p = 0.104$, $d = 0.125$			t(766) = −1.432, $p = 0.153$, $d = -0.105$		
Home value decrease	Actual	250	2.48	1.471	315	***2.58***	1.470
	Assumed	523	2.64	1.421	458	***2.37***	1.388
	t-test statistics	t(771) = 0.240, $p = 0.152$, $d = 0.110$			t(649.378) = −2.015, $p = 0.044$, $d = -0.149$		

Notes: * Bold underlined means indicate actual concern was significantly lower than assumed concern; † Italic, bold, underlined means indicate significantly higher actual concern than assumed concern.

Contrastingly, for 3 out of 8 potential adverse effects (health concerns about pollutants, children's safety, and home value decrease), people with turf swales installed on their streets showed higher concerns than those without (Table 4). In other words, implementation increased concern for these aspects. Effect size (Cohen's d) ranged from 0.145 to 0.224. The concern level difference was the most pronounced for children's safety ($d = -0.224$).

3.4. City/County Differences

For both bioswale types, the average perceived ecosystem benefit showed the same pattern in city/county differences, where participants from NYC perceived significantly higher average ecosystem benefit than those from the other three locations (Figure 3 and Table S8, Section S2).

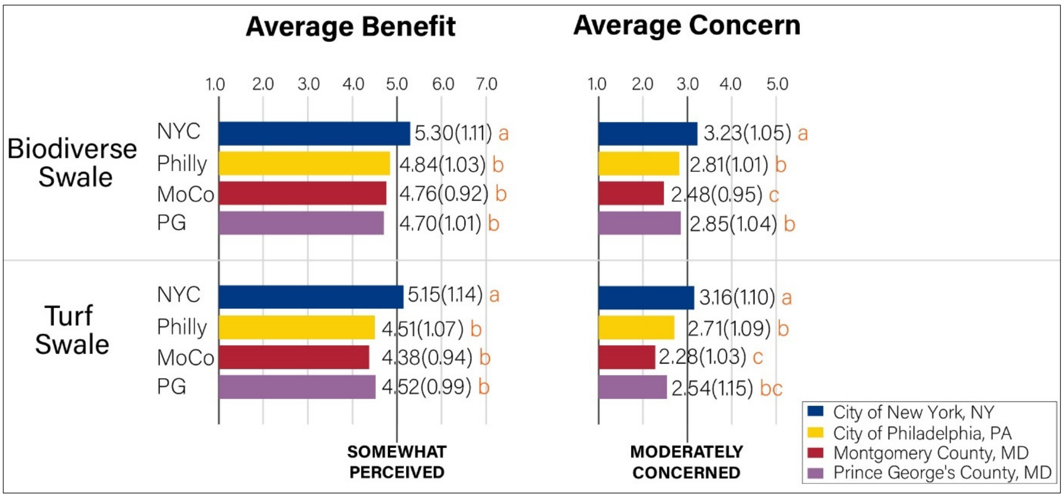

Figure 3. Comparisons of the perceived average benefit and concern for biodiverse and turf swales across the four study areas. #.##(#.##) represents the mean (standard deviation) of average perceived benefit/concern in each area. The differing letters (a–c) indicate significant city/county differences.

Regarding individual benefits, for biodiverse swales, 11 out of 13 measures (except greenspace provision and flood mitigation) showed significant city/county differences (Figure 4 and Table S9, Section S2). For eight of these 11 measures, participants from NYC perceived significantly higher ecosystem benefits than those from the other three locations. For the remaining three measures, only one pairwise difference (NYC > PG) occurred for enhanced neighborhood aesthetics; two pairwise differences (NYC > Philly and NYC > MoCo) occurred for water quality improvement; only one pairwise difference (MoCo > Philly) for habitat value.

Regarding the individual benefits of turf swales, 12 out of 13 measures (except greenspace provision) showed significant city/county differences (Figure 4 and Table S9, Section S2). For 7 of these 12 measures, participants from NYC perceived significantly higher ecosystem benefits than those from the other three locations. For the remaining five measures, only one pairwise difference (NYC > MoCo) occurred for flood mitigation; four pairwise differences (NYC > other three locations and Philly > McCo) for attracting wildlife; two pairwise differences (NYC > Philly and NYC > MoCo) occurred for enhanced neighborhood aesthetics, enhanced neighborhood vitality, and increased property value.

Regarding city/county differences in average concern, biodiverse and turf swales showed slightly different patterns (Figure 3). For biodiverse swales, NYC participants indicated significantly higher average concern than those from all three other locations, whereas MoCo participants showed significantly lower average concern than all three other locations. For turf swales, NYC participants similarly indicated significantly higher average concern than all three other locations, but MoCo participants only showed significantly lower average concern than Philly and NYC.

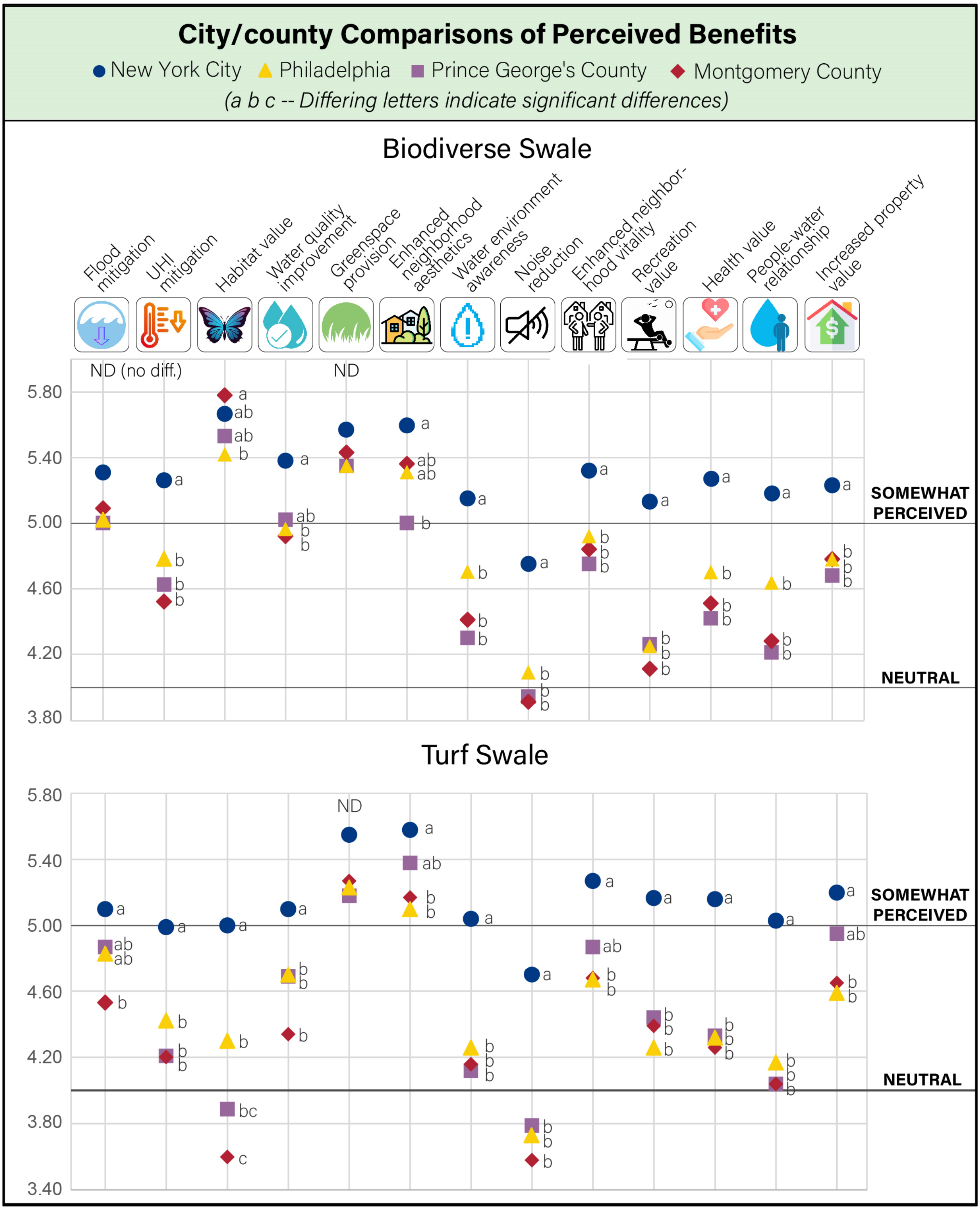

Figure 4. Perceptions of individual benefits of biodiverse and turf swales across the four study areas. ND indicates no significant differences while differing letters (a–c) indicate significant differences.

Regarding city/county differences in individual concerns, biodiverse swales showed a more complex pattern than turf swales (Figure 5 and Table S11, Section S2). For biodiverse swales, in most cases (6 out of 8 concern aspects), NYC participants indicated significantly higher concerns than two or three other locations. In some cases (2 out of 8), MoCo participants showed significantly lower concerns than all three other locations. Concern level was the most similar across cities for "unappealing appearance", with only one pairwise difference (NYC > MoCo). In contrast, for turf swales, the primary pattern (7 out of 8) is that NYC participants indicated significantly higher concerns than all three other locations, with one additional pairwise difference (Philly > MoCo).

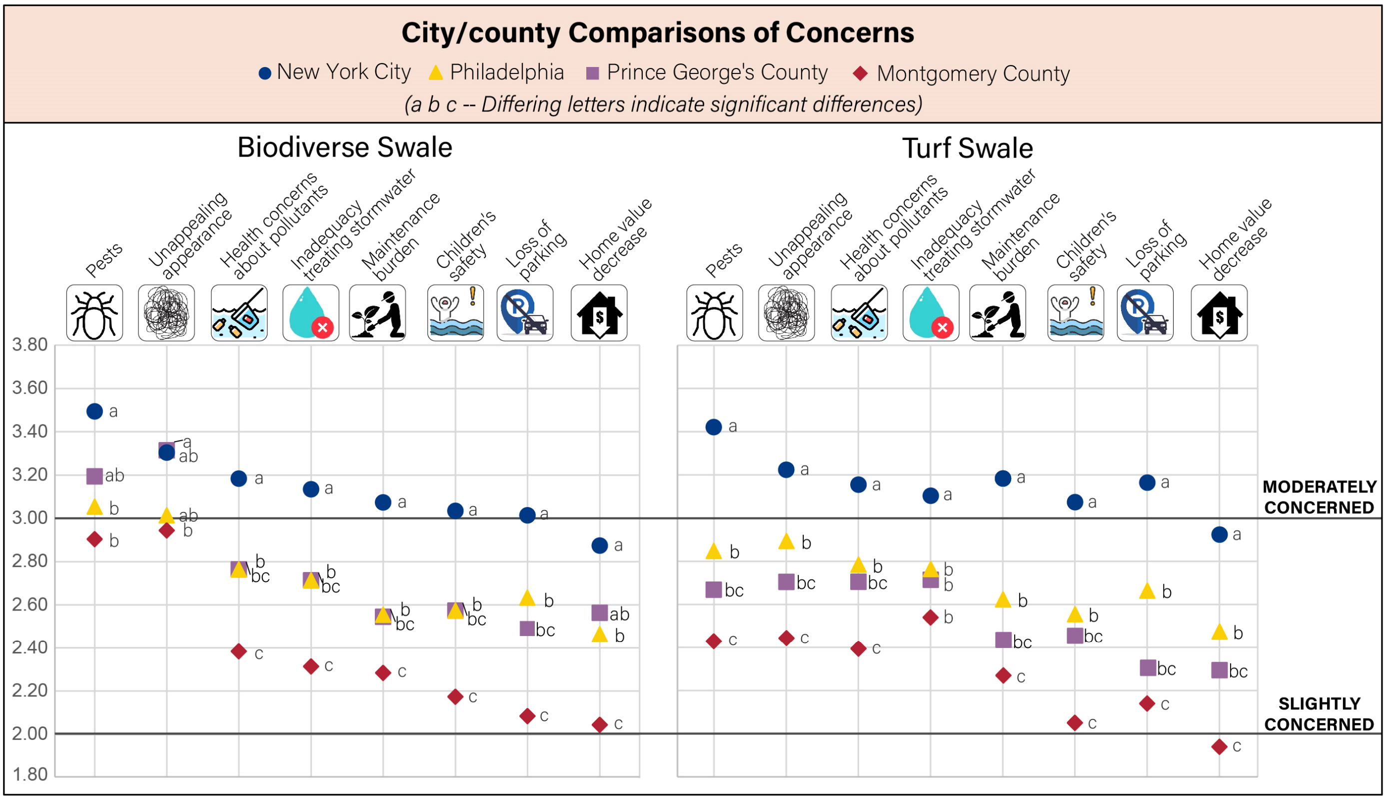

Figure 5. Comparisons of perceptions of individual concerns about biodiverse and turf swales across the four study areas. Differing letters a–c indicate significant differences.

4. Discussion

4.1. Enhanced Ecosystem Benefits from Biodiverse Swales than Turf Swales

Participants in the four study locations recognized certain benefits of both types of bioswales. However, the perception levels were not high (i.e., on average, "somewhat perceived" for biodiverse and between "neutral" and "somewhat perceived" for turf swales), suggesting room for improving the multifaceted functions of bioswales as well as their public understanding. The most widely recognized benefits across both types of bioswales were their contributions to increasing green spaces and enhancing neighborhood aesthetic appeal. Additionally, biodiverse swales were recognized for their habitat, flood mitigation, and water quality improvement benefits. These findings on benefit types align with previous studies. For example, Meenar et al. [48] found that most of the 16 participants they interviewed from the New Jersey Waterfront South neighborhood in Camden, NJ, believed that GSI could beautify the neighborhood. Additionally, many participants highly valued the social benefits of GSI because they viewed it as part of community green space. Miller and Montalto [4] reported a broad perception among NYC GSI practitioners of air quality (not assessed in our study), pollination, waste treatment, global climate regulation, water regulation, and aesthetic benefits from bioswales. Residents familiar with GSI recognized the benefits of aesthetic value, waste treatment, pollination, and water regulation. Most of these benefits echo our findings. Notably, the highest recognition of biodiverse swales' habitat value revealed by our study is encouraging, highlighting public awareness of their crucial role in enhancing urban ecosystems.

Conversely, participants acknowledged turf swales' limitations in delivering environmental benefits, especially UHI mitigation and habitat creation. Additionally, participants perceived both types of bioswales as lacking in certain social benefits (i.e., noise reduction, recreation, raising water environment awareness, and fostering reflection on the people–water relationship). These findings partially align with those of Miller and Montalto [4], where recreation and tourism, noise reduction, and social, spiritual, cultural, and historical value were among the less perceived ecosystem services of bioswales by practitioners and residents. The lack of public recognition of the two benefits of raising water environment awareness and fostering reflection on water relationships is particularly disappointing, as it suggests potential common design failures in bioswales. Existing designs may have fallen short as environmental education tools that evoke personal connections to water. Incorporating educational goals into bioswale design and exploring avenues to disseminate best design practices among professional communities may help improve future designs.

For either type of bioswales, the top three benefits deemed most important by the participants only partially matched the top three most perceived benefits. The alignment was stronger for biodiverse swales where the most important benefits, i.e., flood mitigation, water quality improvement, and habitat value, matched the top three perceived environmental benefits. Conversely, participants only somewhat perceived two of the top three most important turf swale benefits (flood mitigation and water quality improvement), suggesting room for improving the hydrological functions of turf swales.

Comparing the two bioswale types, residents perceived biodiverse swales as providing greater environmental and social benefits than turf swales. This indicates that participants in these municipal areas were sufficiently familiar with biodiverse swales, despite their shorter implementation history than turf swales, to discern their higher ecosystem benefits provision. With that said, turf swales did surpass biodiverse swales in recreational value. This could be influenced by factors such as safety, accessibility, maintenance requirements, aesthetic preferences, and perceived comfort. Turf swales' even, grassy surfaces provide a more familiar and inviting environment for people to engage in recreational activities.

The four municipal areas exhibit both similarities and differences in perception of individual benefits. Perceptions were consistent across all locations for increasing green spaces (by both biodiverse and turf swales) and flood mitigation (by biodiverse swales). However, other benefits varied, often showing a two-tier (or occasionally three-tier) relationship. The overarching trend of NYC surpassing all other locations may be attributed to its high value on green spaces in high-density urban environments. Access to green spaces is particularly critical for relaxation and overall well-being. Therefore, residents may demonstrate greater attention and appreciation for GSI initiatives. The few exceptions where Montgomery County stood out in habitat value perceptions (highest perception for biodiverse swales but lowest for turf swales) are worth noting. This may be related to MoCo's diverse mix of suburban and rural habitats and its proactive approach to environmental education and habitat preservation. Renowned for their strong environmental ethos and commitment to sustainability, the county government and various community organizations actively raise awareness about biodiversity, habitat preservation, and stormwater management through environmental education and outreach programs [49,50]. Residents, therefore, likely have a deeper understanding and appreciation for biodiverse swales' role in supporting wildlife. Similarly, the lowest recognition of turf swales' habitat value reflects the residents' discerning awareness of the trade-offs associated with different green infrastructure approaches. Additionally, NYC and MoCo's higher education and income levels may have also influenced their benefit perceptions [43,51].

The discrepancies—where several actual benefits of biodiverse swales were lower than assumed, but those of turf swales were higher—underscore the need for realistic benefit assessments and alignment between public expectations and the actual performance of GSI. Specifically, biodiverse swales fell short in flood mitigation, water quality, neighborhood vitality, and health benefits, indicating a need for more accurate public communication about their benefits and limitations to better align public perceptions with actual outcomes.

In contrast, the higher actual benefits of turf swales suggest they often perform better than anticipated in several key areas. Understanding why they exceed expectations can help optimize future designs and applications.

In summary, while biodiverse swales were acknowledged to offer greater ecosystem benefits (especially environmental) than turf swales, there remains room to improve public perception and understanding of their diverse roles in urban landscapes. Addressing their limitations and potential for enhancement can guide future design and implementation toward more sustainable and socially beneficial urban environments. Enhancing design to connect infrastructure with people, raise awareness about the urban water environment, and encourage reflection on water relationships is crucial. Moreover, perceptions can vary by context, so understanding these nuances can inform targeted strategies to boost public appreciation and support for biodiverse swale initiatives. By addressing each city's specific needs and challenges, urban planners and policymakers can ensure that biodiverse swales are aesthetically pleasing and functional, as well as valued and embraced by the communities they serve.

4.2. Higher Concerns over Biodiverse Swales than Turf Swales

While concerns regarding bioswale implementation and functionality exist, the overall concern for either type of bioswale was not high (mildly below "moderately concerned"). Among the various expressed concerns, two themes consistently stood out for both bioswale types: pests and unappealing appearance. These concerns align with existing research on residents' fears that GSI's blue-green environment may potentially facilitate pathogen transmissions by certain arthropods (e.g., mosquitoes) [52], as well as their preference for orderly urban landscapes [21]. Regarding pest concerns, a review by Rhodes et al. [52] covering 18 studies since 1992 found no significant difference in the average abundance of mosquito species across three genera when comparing blue-green spaces with non-greened urban spaces. While further research is needed to elucidate the relationship between GSI and pest presence, existing findings should be more effectively communicated to residents to alleviate concerns. With regard to aesthetic concerns, studies have shown that public education is an effective means to cultivate ecological aesthetics by helping residents recognize the myriad benefits offered by more diverse plant communities as opposed to those dominated by turf [21,53].

An interesting paradox emerged regarding participants' high aesthetic concern despite strongly recognizing biodiverse swales' aesthetic benefits. A subsequent Pearson correlation test between the neighborhood aesthetic benefit and unappealing appearance unveiled a statistically significant negative relationship ($r = -0.195$, $p < 0.001$), indicating that individuals who acknowledge the benefit tend to have a lower concern. Nonetheless, strong negative sentiments about the unappealing aesthetics persisted, resulting in a high average concern among the sampled population. This underscores a clear opportunity to address the aesthetic concern through targeted research, education, and outreach efforts.

Besides pests and unappealing appearance, participants showed valid worries about pollutant accumulation in biodiverse swales and their potential inadequacy in treating stormwater despite recognizing their water quality improvement benefit. Literature has highlighted these as unintended consequences of GSI for a wide range of reasons [54], such as shifts in water chemistry causing pollutant release, winter salt mobilizing metals [55], fine particles clogging soil media, improper maintenance importing excessive nutrients [56], and plant mortality compromising treatment efficiency. It is imperative to explore mechanisms for regularly assessing pollutant accumulation and its health implications, along with devising maintenance strategies to mitigate health risks posed by pollutants. Additionally, because the long-term fate and transport potentials of many pollutants in GSI remain poorly understood [54], scientific inquiries must progress to clarify pollutant removal dynamics in bioswales and improve their design. Scholars should also leverage research findings to advance environmental education efforts, bridging the gap between scientific understanding of bioswale functionality and public concerns.

On a positive note, the study reveals low concerns about home value decrease, loss of parking, children's safety, and maintenance burdens associated with both types of bioswales. These concerns, prevalent in the early years of bioswale implementation, seem to have been effectively addressed through two decades of implementation, design improvements, policy reform, and environmental education. Some, such as home value outcomes, are supported by literature. Venkataramanan's review [41] of 13 studies on economic outcomes reported an overall positive association between green infrastructure and property values. In contrast, the finding that residents were not concerned about the maintenance burden falling on them conflicts with Venkataramanan's review [41], which highlighted concern about GSI maintenance as the most salient theme. This indicates that the four studied municipal areas likely have been effectively managing maintenance responsibilities without overreliance on the residents themselves.

Interestingly, the levels of concern over biodiverse swales were higher than turf swales concerning pests, appearance, pollutant accumulation, children's safety, and home value decrease. We suspect this inclination is related to biodiverse swales' denser and more diverse vegetation, higher difficulty maintaining an orderly appearance, and potentially lower visibility inside the facility.

Regarding city/county differences in concerns, the overarching three-tier (occasionally two-tier) relationship for both types of bioswales could be partially explained by differences in urban environments (as discussed in benefit perception), sample population demographics, and environmental education efforts. NYC's diverse and educated population may be more attuned to environmental issues, cognizant of the complexities surrounding green infrastructure implementation, and sensitive to potential drawbacks. Additionally, the city's vibrant civic culture encourages residents to be more vocal in expressing concerns about urban development and sustainability initiatives. In contrast, the generally lowest concerns in Montgomery County can be attributed to its lower-density environment, higher education and income levels among the sample population, and greater familiarity with GSI contributed by environmental education and outreach programs. Interestingly, this suggests that participants' demographic characteristics (e.g., education and income) may interact with other factors (e.g., urban environment characteristics) to shape different levels of concern. However, these interpretations need to be verified with future studies.

Finally, the comparisons between assumed and actual concerns revealed an intriguing opportunity to use implementation to advocate for biodiverse swales. The fact that implementation alleviated concerns about most (6 out of 8) potential adverse effects, especially pests, indicates that exposure to biodiverse swales alone can alleviate initial apprehensions, making them more acceptable and appreciated by the public over time. On the contrary, despite a weaker trend than biodiverse swales, implementation increasing concerns about turf swales for some (3 out of 8) effects suggests that turf swales don't effectively address these issues in practice.

In summary, the overall low concerns about bioswale implementation are encouraging, suggesting that the public is generally receptive to this green infrastructure solution. However, the highest concerns over pests and unappealing appearance underscore the importance of ongoing maintenance and targeted outreach and education. Differences in urban environments, environmental consciousness levels, and demographics may have contributed to the generally highest concerns in NYC and lowest in Montgomery County. Additionally, the implementation of biodiverse swales has the potential to mitigate most worries, suggesting that public exposure and education can improve acceptance.

4.3. Study Limitations

Despite essential findings and practical implications, we note several study limitations. First, the studied environmental benefits and concerns may not be comprehensive. Future studies can include additional benefits such as air quality improvement and carbon emissions reduction, as well as other concerns such as gentrification. Second, as with other sampling approaches, the representativeness of the participants of the broader population cannot be assured. We captured a relatively highly educated, older population. Inferences to other groups and geographies should be conservative.

5. Conclusions

Through an online survey, we assessed residents' perceptions of ecosystem benefits and concerns regarding two types of bioswales in four municipal areas. We found that both bioswale types were recognized for enhancing green spaces and neighborhood aesthetics. Residents perceived higher environmental and social benefits from biodiverse swales than turf swales, particularly for their contributions to habitat provision. While overall concerns for both types of bioswales were low, potential pest cultivation and the unappealing appearance of biodiverse swales remain significant perceptive barriers to address. The research also pointed to an intriguing trend where implementing biodiverse swales alleviated initial concerns, especially about pests, indicating that exposure and familiarity can lead to greater acceptance over time. Location-specific differences in both benefit and concern perception were also observed, with NYC participants generally exhibiting higher levels of both perceived benefits and concerns compared to the other areas and Montgomery County participants generally exhibiting the lowest concern. This variance can be attributed to the distinct urban environments, levels of environmental awareness, and demographic profiles in these areas.

This study is among the first to provide a nuanced understanding of public perceptions regarding the ecosystem benefits and concerns associated with bioswales. It also distinguishes between actual and assumed perceptions, shedding light on the potential impact of former implementation. Additionally, the comparisons of multiple municipal areas highlight how various urban contexts and demographic factors may affect perceptions, allowing us to identify tailored public engagement and education strategies to enhance GSI implementation and benefit perception. Importantly, we confirmed that while residents recognized the significant biodiversity benefits of biodiverse swales, they remain significantly concerned about their potential to harbor pests and their unappealing appearances. Pilot projects and incremental implementation, as evidenced in our findings, could be effective strategies for overcoming resistance. Moreover, continuous public education, rigorous maintenance, and adaptive design remain essential for maximizing the benefits and minimizing the drawbacks of biodiverse swales.

As urban areas grapple with escalating environmental challenges driven by climate change and aging infrastructure, GSI represents a vital solution for enhancing urban ecosystem health and delivering tangible benefits to the public. Investing in GSI, particularly in biodiverse swales, is essential not only for addressing immediate stormwater challenges but also for promoting long-term ecological resilience. Effective design and maintenance of biodiverse swales, coupled with robust public engagement and education initiatives, are crucial to success. Additionally, integrating adaptive management strategies will allow continuous improvement based on evolving environmental conditions and community feedback. Ultimately, these efforts can lead to vibrant, sustainable urban environments that not only mitigate flooding and improve water quality but also enrich residents' lives through increased biodiversity and enhanced quality of life.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w16202899/s1. Section S1: Survey Instrument; Section S2: Supplementary Tables; Table S1: City/county comparisons on demographic characteristics; Table S2: Comparisons across the four individual environmental benefits of biodiverse and turf swales; Table S3: Comparisons across the eight individual social benefits of biodiverse and turf swales; Table S4: Comparisons across the 13 benefits of biodiverse and turf swales; Table S5: Comparisons of perceived benefits between biodiverse and turf swales; Table S6: Comparisons across the eight concerns of biodiverse and turf swales; Table S7: Comparisons of perceived concerns between biodiverse and turf swales; Table S8: City/county comparisons of the aggregated mean of 13 benefits for biodiverse and turf swales; Table S9: City/county comparisons of individual benefit perception for biodiverse and turf swales (only the measures with significant differences are shown); Table S10: City/county comparisons of the aggregated mean of concerns for biodiverse and turf swales; Table S11: City/county comparisons of individual concern for biodiverse and turf swales (only the measures with significant differences are shown).

Author Contributions: Conceptualization, H.W. and M.C.H.; methodology, H.W., R.W., M.C.H. and K.M.K.; formal analysis, H.W.; investigation, M.C.H.; resources, M.C.H.; data curation, M.C.H. and K.M.K.; writing—original draft preparation, H.W., M.C.H. and M.A.; writing—review and editing, H.W. and K.M.K.; visualization, H.W.; project administration, H.W.; funding acquisition, M.C.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on the OPEN ICPSR repository at: https://www.openicpsr.org/openicpsr/project/208902/version/V1/view (accessed on 4 September 2024).

Acknowledgments: This research was supported by Penn State Sustainability Institute's Mainstreaming Biodiversity in a Decade of Action Seed Grant. We also wish to acknowledge the Journal Editor and two anonymous reviewers whose thoughtful comments helped improve the manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. United Nations. *The United Nations World Water Development Report 2020: Water and Climate Change*; United Nations: New York, NY, USA, 2020.
2. McPhillips, L.E.; Matsler, A.M. Temporal Evolution of Green Stormwater Infrastructure Strategies in Three US Cities. *Front. Built Environ.* **2018**, *4*, 26. [CrossRef]
3. Keeley, M.; Koburger, A.; Dolowitz, D.P.; Medearis, D.; Nickel, D.; Shuster, W. Perspectives on the Use of Green Infrastructure for Stormwater Management in Cleveland and Milwaukee. *Environ. Manag.* **2013**, *51*, 1093–1108. [CrossRef] [PubMed]
4. Miller, S.M.; Montalto, F.A. Stakeholder Perceptions of the Ecosystem Services Provided by Green Infrastructure in New York City. *Ecosyst. Serv.* **2019**, *37*, 100928. [CrossRef]
5. Prudencio, L.; Null, S.E. Stormwater Management and Ecosystem Services: A Review. *Environ. Res. Lett.* **2018**, *13*, 033002. [CrossRef]
6. Demuzere, M.; Orru, K.; Heidrich, O.; Olazabal, E.; Geneletti, D.; Orru, H.; Bhave, A.G.; Mittal, N.; Feliu, E.; Faehnle, M. Mitigating and Adapting to Climate Change: Multi-Functional and Multi-Scale Assessment of Green Urban Infrastructure. *J. Environ. Manag.* **2014**, *146*, 107–115. [CrossRef]
7. Wang, R.; Wu, H.; Chiles, R. Ecosystem Benefits Provision of Green Stormwater Infrastructure in Chinese Sponge Cities. *Environ. Manag.* **2022**, *69*, 558–575. [CrossRef]
8. Choi, C.; Berry, P.; Smith, A. The Climate Benefits, Co-Benefits, and Trade-Offs of Green Infrastructure: A Systematic Literature Review. *J. Environ. Manag.* **2021**, *291*, 112583. [CrossRef]
9. Perrelet, K.; Moretti, M.; Dietzel, A.; Altermatt, F.; Cook, L.M. Engineering Blue-Green Infrastructure for and with Biodiversity in Cities. *npj Urban Sustain.* **2024**, *4*, 27. [CrossRef]
10. Filazzola, A.; Shrestha, N.; MacIvor, J.S. The Contribution of Constructed Green Infrastructure to Urban Biodiversity: A Synthesis and Meta-Analysis. *J. Appl. Ecol.* **2019**, *56*, 2131–2143. [CrossRef]
11. West, C.; Wu, H. The Next Green Revolution: Rebuilding Urban Abundance through Plant Community-Based Design. *Landsc. Archit.* **2020**, *27*, 8–24. [CrossRef]
12. Miller, J.R.; Hobbs, R.J. Conservation where People Live and Work. *Conserv. Biol.* **2002**, *16*, 330–337. [CrossRef]
13. Connop, S.; Vandergert, P.; Eisenberg, B.; Collier, M.J.; Nash, C.; Clough, J.; Newport, D. Renaturing Cities Using a Regionally-Focused Biodiversity-Led Multifunctional Benefits Approach to Urban Green Infrastructure. *Environ. Sci. Policy* **2016**, *62*, 99–111. [CrossRef]
14. IPBES. *Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*; Zenodo: Geneva, Switzerland, 2019.
15. Winfrey, B.K.; Payne, E.G.I.; Ambrose, R.F. Understanding the Roles of Biodiversity and Functional Diversity in Provision of Co-Benefits by Stormwater Biofilter Plant Communities. In Proceedings of the International Low Impact Development Conference 2018, Nashville, TN, USA, 12–15 August 2018; pp. 203–212. [CrossRef]
16. Winfrey, B.K.; Hatt, B.E.; Ambrose, R.F. Biodiversity and Functional Diversity of Australian Stormwater Biofilter Plant Communities. *Landsc. Urban Plan.* **2018**, *170*, 112–137. [CrossRef]
17. Técher, D.; Berthier, E. Supporting Evidences for Vegetation-Enhanced Stormwater Infiltration in Bioretention Systems: A Comprehensive Review. *Environ. Sci. Pollut. Res.* **2023**, *30*, 19705–19724. [CrossRef]

18. Heidari, B.; Randle, S.; Minchillo, D.; Jaber, F.H. Green Stormwater Infrastructure: A Critical Review of the Barriers and Solutions to Widespread Implementation. *WIREs Water* **2023**, *10*, e1625. [CrossRef]
19. Qi, J.; Barclay, N. Social Barriers and the Hiatus from Successful Green Stormwater Infrastructure Implementation across the US. *Hydrology* **2021**, *8*, 10. [CrossRef]
20. Meenar, M.; Howell, J.P.; Moulton, D.; Walsh, S. Green Stormwater Infrastructure Planning in Urban Landscapes: Understanding Context, Appearance, Meaning, and Perception. *Land* **2020**, *9*, 534. [CrossRef]
21. Cholakis-Kolysko, K. One Neighbor's Curb Garden, Another's Weedy Pit: Municipal and Designer Perspectives on Public Perception of Green Street Rain Garden Appearance. Master's Thesis, The Pennsylvania State University, University Park, PA, USA, 2022.
22. Everett, G.; Lawson, E.; Lamond, J. Green Infrastructure and Urban Water Management. In *Handbook on Green Infrastructure*; Edward Elgar Publishing: Cheltenham, UK, 2015.
23. Byrne, J.A.; Lo, A.Y.; Jianjun, Y. Residents' Understanding of the Role of Green Infrastructure for Climate Change Adaptation in Hangzhou, China. *Landsc. Urban Plan.* **2015**, *138*, 132–143. [CrossRef]
24. Barnhill, K.; Smardon, R. Gaining Ground: Green Infrastructure Attitudes and Perceptions from Stakeholders in Syracuse, New York. *Environ. Pract.* **2012**, *14*, 6–16. [CrossRef]
25. Homet, K.; Kremer, P.; Smith, V.; Strader, S. Multi-Variable Assessment of Green Stormwater Infrastructure Planning across a City Landscape: Incorporating Social, Environmental, Built-Environment, and Maintenance Vulnerabilities. *Front. Environ. Sci.* **2022**, *10*, 958704. [CrossRef]
26. Venkataramanan, V.; Lopez, D.; McCuskey, D.J.; Kiefus, D.; McDonald, R.I.; Miller, W.M.; Packman, A.I.; Young, S.L. Knowledge, Attitudes, Intentions, and Behavior Related to Green Infrastructure for Flood Management: A Systematic Literature Review. *Sci. Total Environ.* **2020**, *720*, 137606. [CrossRef] [PubMed]
27. Church, S.P. Exploring Green Streets and Rain Gardens as Instances of Small Scale Nature and Environmental Learning Tools. *Landsc. Urban Plan.* **2015**, *134*, 229–240. [CrossRef]
28. Chini, C.M.; Canning, J.F.; Schreiber, K.L.; Peschel, J.M.; Stillwell, A.S. The Green Experiment: Cities, Green Stormwater Infrastructure, and Sustainability. *Sustainability* **2017**, *9*, 105. [CrossRef]
29. Brown, H.L.; Bos, D.G.; Walsh, C.J.; Fletcher, T.D.; RossRakesh, S. More than Money: How Multiple Factors Influence Householder Participation in at-Source Stormwater Management. *J. Environ. Plan. Manag.* **2016**, *59*, 79–97. [CrossRef]
30. Turner, V.K.; Jarden, K.; Jefferson, A. Resident Perspectives on Green Infrastructure in an Experimental Suburban Stormwater Management Program. *Cities Environ.* **2016**, *9*, 4.
31. Cote, S.A.; Wolfe, S.E. Assessing the Social and Economic Barriers to Permeable Surface Utilization for Residential Driveways in Kitchener, Canada. *Environ. Pract.* **2014**, *16*, 6–18. [CrossRef]
32. Derkzen, M.L.; van Teeffelen, A.J.A.; Verburg, P.H. Green Infrastructure for Urban Climate Adaptation: How Do Residents' Views on Climate Impacts and Green Infrastructure Shape Adaptation Preferences? *Landsc. Urban Plan.* **2017**, *157*, 106–130. [CrossRef]
33. Rajapaksa, D.; Islam, M.; Managi, S. Pro-Environmental Behavior: The Role of Public Perception in Infrastructure and the Social Factors for Sustainable Development. *Sustainability* **2018**, *10*, 937. [CrossRef]
34. Kollmuss, A.; Agyeman, J. Mind the Gap: Why Do People Act Environmentally and What Are the Barriers to pro-Environmental Behavior? *Environ. Educ. Res.* **2002**, *8*, 239–260. [CrossRef]
35. Ando, A.W.; Netusil, N.R. Valuing the Benefits of Green Stormwater Infrastructure. In *Oxford Research Encyclopedia of Environmental Science*; Oxford University Press: Oxford, UK, 2018; ISBN 978-0-19-938941-4.
36. Baptiste, A.K.; Foley, C.; Smardon, R. Understanding Urban Neighborhood Differences in Willingness to Implement Green Infrastructure Measures: A Case Study of Syracuse, NY. *Landsc. Urban Plan.* **2015**, *136*, 1–12. [CrossRef]
37. Barclay, N.; Klotz, L. Role of Community Participation for Green Stormwater Infrastructure Development. *J. Environ. Manag.* **2019**, *251*, 109620. [CrossRef]
38. Wang, R.; Brent, D.; Wu, H. Willingness to Pay for Ecosystem Benefits of Green Stormwater Infrastructure in Chinese Sponge Cities. *J. Clean. Prod.* **2022**, *371*, 133462. [CrossRef]
39. Elliott, R.M.; Motzny, A.E.; Majd, S.; Chavez, F.J.V.; Laimer, D.; Orlove, B.S.; Culligan, P.J. Identifying Linkages between Urban Green Infrastructure and Ecosystem Services Using an Expert Opinion Methodology. *Ambio* **2020**, *49*, 569–583. [CrossRef] [PubMed]
40. Kondo, M.C.; Low, S.C.; Henning, J.; Branas, C.C. The Impact of Green Stormwater Infrastructure Installation on Surrounding Health and Safety. *Am. J. Public Health* **2015**, *105*, E114–E121. [CrossRef] [PubMed]
41. Venkataramanan, V.; Packman, A.I.; Peters, D.R.; Lopez, D.; McCuskey, D.J.; McDonald, R.I.; Miller, W.M.; Young, S.L. A Systematic Review of the Human Health and Social Well-Being Outcomes of Green Infrastructure for Stormwater and Flood Management. *J. Environ. Manag.* **2019**, *246*, 868–880. [CrossRef] [PubMed]
42. Suppakittpaisarn, P.; Jiang, X.; Sullivan, W.C. Green Infrastructure, Green Stormwater Infrastructure, and Human Health: A Review. *Curr. Landsc. Ecol. Rep.* **2017**, *2*, 96–110. [CrossRef]
43. Spahr, K.M.; Smith, J.M.; McCray, J.E.; Hogue, T.S. Reading the Green Landscape: Public Attitudes toward Green Stormwater Infrastructure and the Perceived Nonmonetary Value of Its Co-Benefits in Three US Cities. *J. Sustain. Water Built Environ.* **2021**, *7*, 04021017. [CrossRef]

44. Rainey, W.; McHale, M.; Arabi, M. Characterization of Co-Benefits of Green Stormwater Infrastructure across Ecohydrologic Regions in the United States. *Urban For. Urban Green.* **2022**, *70*, 127514. [CrossRef]
45. Wilbers, G.-J.; de Bruin, K.; Seifert-Dähnn, I.; Lekkerkerk, W.; Li, H.; Budding-Polo Ballinas, M. Investing in Urban Blue–Green Infrastructure—Assessing the Costs and Benefits of Stormwater Management in a Peri-Urban Catchment in Oslo, Norway. *Sustainability* **2022**, *14*, 1934. [CrossRef]
46. National Association of City Transportation Officials Urban Street Design Guide—Bioswales. Available online: https://nacto.org/publication/urban-street-design-guide/street-design-elements/stormwater-management/bioswales/ (accessed on 30 August 2024).
47. Kelley, K.; Todd, M.; Hopfer, H.; Centinari, M. Identifying Wine Consumers Interested in Environmentally Sustainable Production Practices. *Int. J. Wine Bus. Res.* **2021**, *34*, 86–111. [CrossRef]
48. Meenar, M.; Heckert, M.; Adlakha, D. "Green Enough Ain't Good Enough:" Public Perceptions and Emotions Related to Green Infrastructure in Environmental Justice Communities. *Int. J. Environ. Res. Public Health* **2022**, *19*, 1448. [CrossRef] [PubMed]
49. Gmoser-Daskalakis, K. *Incentivizing Private Property Green Infrastructure: Recommendations for Los Angeles County*; University of California Los Angeles Luskin Center for Innovation: Los Angeles, CA, USA, 2019.
50. Benedict, M.A.; McMahon, E.T.; Fund, M.A.T.C. *Green Infrastructure: Linking Landscapes and Communities*; Island Press: Washington, DC, USA, 2012; ISBN 978-1-59726-764-9.
51. Brent, D.A.; Gangadharan, L.; Lassiter, A.; Leroux, A.; Raschky, P.A. Valuing Environmental Services Provided by Local Stormwater Management. *Water Resour. Res.* **2017**, *53*, 4907–4921. [CrossRef]
52. Rhodes, C.G.; Scavo, N.A.; Finney, M.; Fimbres-Macias, J.P.; Lively, M.T.; Strauss, B.H.; Hamer, G.L. Meta-Analysis of the Relative Abundance of Nuisance and Vector Mosquitoes in Urban and Blue-Green Spaces. *Insects* **2022**, *13*, 271. [CrossRef] [PubMed]
53. Cole, L.B.; McPhearson, T.; Herzog, C.P.; Russ, A. Green Infrastructure. In *Urban Environmental Education Review*; Russ, A., Krasny, M.E., Russ, A., Eds.; Cornell University Press: Ithaca, NY, USA, 2017; ISBN 978-1-5017-0582-3.
54. Taguchi, V.J.; Weiss, P.T.; Gulliver, J.S.; Klein, M.R.; Hozalski, R.M.; Baker, L.A.; Finlay, J.C.; Keeler, B.L.; Nieber, J.L. It Is Not Easy Being Green: Recognizing Unintended Consequences of Green Stormwater Infrastructure. *Water* **2020**, *12*, 522. [CrossRef]
55. Paus, K.H.; Morgan, J.; Gulliver, J.S.; Leiknes, T.; Hozalski, R.M. Effects of Temperature and NaCl on Toxic Metal Retention in Bioretention Media. *J. Environ. Eng.* **2014**, *140*, 04014034. [CrossRef]
56. Small, G.; Shrestha, P.; Metson, G.S.; Polsky, K.; Jimenez, I.; Kay, A. Excess Phosphorus from Compost Applications in Urban Gardens Creates Potential Pollution Hotspots. *Environ. Res. Commun.* **2019**, *1*, 091007. [CrossRef]