Carbon sequestration of bioretention cells and green roofs

Séquestration du carbone par les bassins de biorétention et les toitures végétalisées

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RÉSUMÉ

Les infrastructures bleues et vertes (IBV) fournissent des services importants qui aident les villes à s'adapter au changement climatique, comme la réduction de l'effet d'îlot de chaleur urbain et du risque d'inondation. Beaucoup moins d'études ont été consacrées à leur capacité à atténuer le changement climatique par la séquestration du carbone, en particulier dans les climats froids. Dans cette présentation, nous présentons les premiers résultats d'un programme de suivi en cours à Reykjavík, où les flux de carbone ont été mesurés dans deux bassins de biorétention, deux toitures végétalisées extensives et une pelouse urbaine de référence. Nous examinons également l'importance des variables environnementales, telles que le rayonnement photosynthétiquement actif (PAR), la température du sol, la teneur en eau, la température de l'air et la vitesse du vent, dans la séquestration du carbone. Les résultats de la période de suivi 2025–2026 indiquent que les bassins de biorétention dotés de matériaux filtrants plus profonds ont séquestré du carbone pendant la période de suivi. Les toitures végétalisées extensives peu profondes ont montré un potentiel de séquestration plus faible, tandis que la pelouse urbaine de référence présentait une forte assimilation, mais aussi des pertes respiratoires plus élevées.

ABSTRACT

Blue-green infrastructure (BGI) provides important services that help cities adapt to climate change, such as reducing the heat-island effect and flood risk. Much less has been reported on its ability to mitigate climate change through carbon sequestration, especially in cold climates. In this presentation, we present initial results from an ongoing monitoring program in Reykjavík, where carbon fluxes were measured in two bioretention cells, two extensive green roofs, and an urban grass lawn reference site. We also consider the importance of environmental predictors, such as photosynthetically active radiation (PAR), soil temperature, moisture content, air temperature, and wind speed, in carbon sequestration. The results from the 2025–2026 monitoring period indicate that bioretention cells with deeper engineered filter media sequestered carbon during the monitoring period. Shallow extensive green roofs showed lower sequestration potential, while the urban grass reference site had high assimilation but also higher respiration losses.

KEYWORDS

Carbon sequestration potential, bioretention cells, climate change, green roofs, nature-based stormwater solutions.

1 INTRODUCTION

Blue green infrastructure (BGI) is both considered an adaptation and mitigation for climate change. While BGI's potential for reducing flood risk has been studied considerably (e.g. Zaqout and Andradóttir, 2021), their carbon sequestration potential remains unquantified. The few urban studies have produced mixed results (Kinnunen, 2024): For example, Velasco et al. (2018) reported that green areas sequestered 4% of total carbon dioxide emissions in Mexico City but emitted 1% in Singapore on annual basis. This difference was attributed to abiotic site factors, such as the soil and weather conditions, as well as biotic factors like the local vegetation. Fine-grained soils were found to sequester more carbon than coarse-grained soils (Hartley et al., 2021; Sosa-Hernández et al., 2019). This highlights the importance of measuring carbon sequestration locally, and not only during the warm season but also during winter vegetation and microbial dormancy. The goal of this study was to assess the carbon sequestration potential of newly built bioretention cells and mature green roofs with reference to a typical urban grass lawn with a particular focus on dark and freezing winter months characterized by intermittent frost and rain on snow (Andradóttir et al., 2021). The study was performed in Iceland where the soils are volcanic, known to have high infiltration potential as well as low drainage capacity (Zaqout and Andradóttir, 2021).

2 METHODS

2.1 Experimental sites

The five measurement sites located at the University of Iceland campus (Table 1) include two bioretention cells built according to best practices, with engineered local soils, a drainage layer and underdrain. Two extended green roofs built 7-10 years ago, with shallow (<7 cm) filter media, thereof at least one following the local practice of using grass turf turned upside down. These four BGIs had a commercially available grass turf with slowly growing local native herbaceous species, chosen because of its biodiversity value and low maintenance needs. Bioretention cell A, also included additional forb and shrub species, such as Wolly Willow (*Salix lanata)*, Wood Cranesbill (*Geranium sylvaticum*) and Water Avens (Geum rivale), to form a more functionally diverse turf including more deep-rooted species. The original grass lawn was used as a reference of the typical green surfaces in the urban setting, with faster growing grass and no underdrain. In each site, 6 rings were permanently installed to resolve some of the natural variability within each site.

Table 1. Study site characteristics

Site	Identifier	Year Built	Vegetation	Filter media	Drainage	Underdrain	Nr. of rings
Bioretention Cells*	BRC-A	2024	Native grass turf with deep-rooted species	45 cm mixture (70% sand, 30% local soil)	25 cm gravel	10 cm diameter drainage pipe	6
	BRC-B	2024	Native grass turf				6
Extensive green roof	GR-A	2017	Native grass turf	None	None	None	6
	GR-B	2015	Grass turf (with natural selection of low nutrient species)	Inverted turf, 5 cm thick	Dimpled plastic membrane		4
Urban Grass	UGS	1980s-	Urban grass lawn (original)	45-70 cm local soils	None	None	6

*Roof-water inflow was not connected during the first two monitoring years due to site-development constraints and to allow vegetation establishment.

2.2 Field monitoring

Following the methods used to estimate Iceland's LULUCF carbon emissions as part of the country's commitments to the Paris Agreement, net CO_2 fluxes and respiration were monitored weekly over 120 seconds using an EGM-5 portable gas analyzer with a CPY-5 canopy chamber, which also measures solar radiation (PP Systems, Amesbury, USA). Measurements were conducted on relatively dry and calm days. Soil moisture and temperature were continuously monitored at three depths, 5 cm, 15 cm, and 35 cm, at two locations within each bioretention cell. Wind speed, soil and air temperature, and solar radiation data were obtained from the Icelandic Meteorological Office. More information on field monitoring is presented in Muneeb (2025).

2.3 Data analyses

Linear and quadratic carbon sequestration fluxes were derived from the measured change in CO_2 concentration within the canopy chamber. To account for possible leakage, the higher value was used as the representative value for net carbon sequestration (NEP), while the lower value was used for respiration. Assimilation was calculated as the difference between NEP and respiration. Data were quality tested, and outliers were removed. Environmental indicators were first assessed using simple regression. Multi-parameter models were used only when they improved predictive power. Data collected during vegetation dormancy, defined using a 4 °C air-temperature threshold, were treated separately. Annual sequestration rates were predicted from these regression models using 10 years of weather and soil data from Reykjavík.

3 PRELIMINARY RESULTS

An overview of the 2025–2026 monitoring period is presented for Bioretention Cell A in Figure 1. The highest assimilation and respiration rates occurred during the peak summer months. The bioretention cell acted as a net carbon sink until the dormancy period, when fluxes were minimal and showed limited correlation with atmospheric and soil conditions.

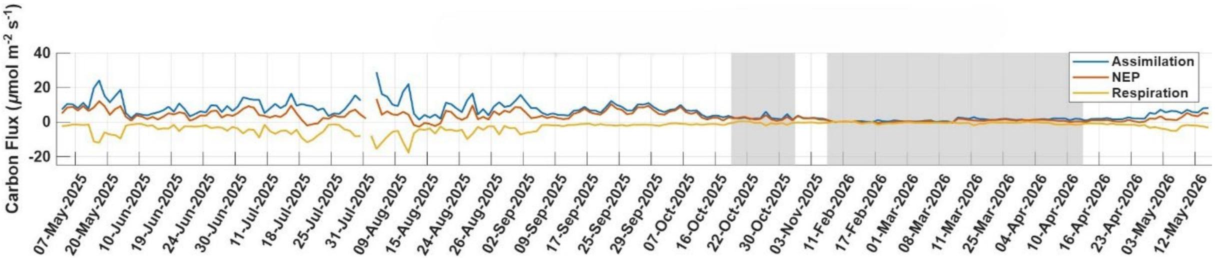
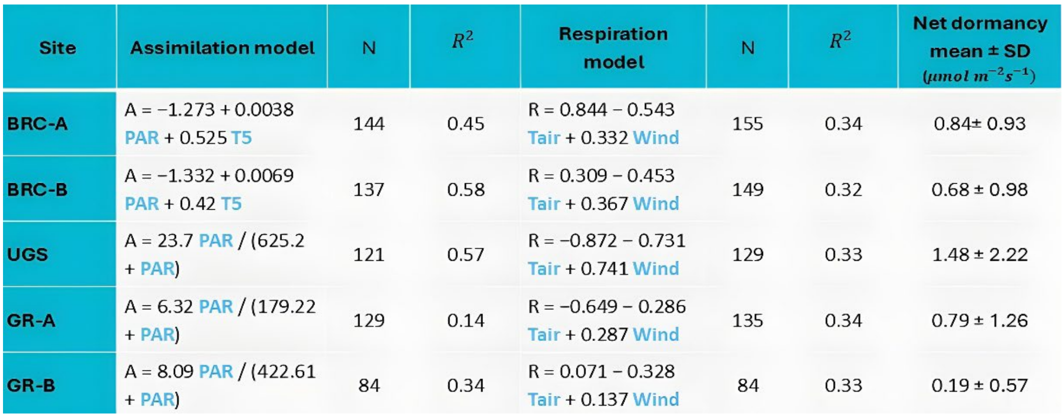


Figure 1. Time series of carbon-flux components for Bioretention Cells A during the 2025–2026 monitoring period. Shaded areas indicate dormancy campaigns with ambient air temperature below 4 °C.

During the growing season, PAR and soil temperature at 5 cm were the best predictors for assimilation at all sites. Ambient air temperature and wind speed were identified as the best predictors for respiration. Linear models, or alternatively Michaelis–Menten models when based only on PAR, captured 30–60% of the variance in the bioretention cells and up to 30% in the green roofs (Table 2). During the dormancy period, average flux values were used as representative estimates. All sites acted on average as a carbon sink during winter (Table 2).

Table 2. Predicted models for assimilation and respiration during the growing season (in μmol m^{-2} s^{-1}), and average net ecosystem production (NEP) used as representative values for the dormancy period.



Site	Assimilation model	N	R^2	Respiration model	N	R^2	Net dormancy mean ± SD ($\mu mol\ m^{-2}s^{-1}$)
BRC-A	A = −1.273 + 0.0038 PAR + 0.525 T5	144	0.45	R = 0.844 − 0.543 Tair + 0.332 Wind	155	0.34	0.84± 0.93
BRC-B	A = −1.332 + 0.0069 PAR + 0.42 T5	137	0.58	R = 0.309 − 0.453 Tair + 0.367 Wind	149	0.32	0.68 ± 0.98
UGS	A = 23.7 PAR / (625.2 + PAR)	121	0.57	R = −0.872 − 0.731 Tair + 0.741 Wind	129	0.33	1.48 ± 2.22
GR-A	A = 6.32 PAR / (179.22 + PAR)	129	0.14	R = −0.649 − 0.286 Tair + 0.287 Wind	135	0.34	0.79 ± 1.26
GR-B	A = 8.09 PAR / (422.61 + PAR)	84	0.34	R = 0.071 − 0.328 Tair + 0.137 Wind	84	0.33	0.19 ± 0.57

Notes: Statistical significance of models was p<<0.001.

PAR = photosynthetically active radiation, T5 = soil temperature at 5 cm, Tair = air temperature, and Wind = wind speed.

Using the statistical models presented in Table 2, annual carbon sequestration rates for the bioretention cells were projected using historical meteorological and soil data from 2009–2018. These initial findings suggest that the two bioretention cells bind similar amounts of carbon on an annual basis as the more mature urban grass lawn, but their net carbon storage is greater because of lower respiration losses (Figure 2). The extensive green roofs, with only 7–10 cm of filter media, sequestered carbon about half of the carbon compared to the bioretention cells.

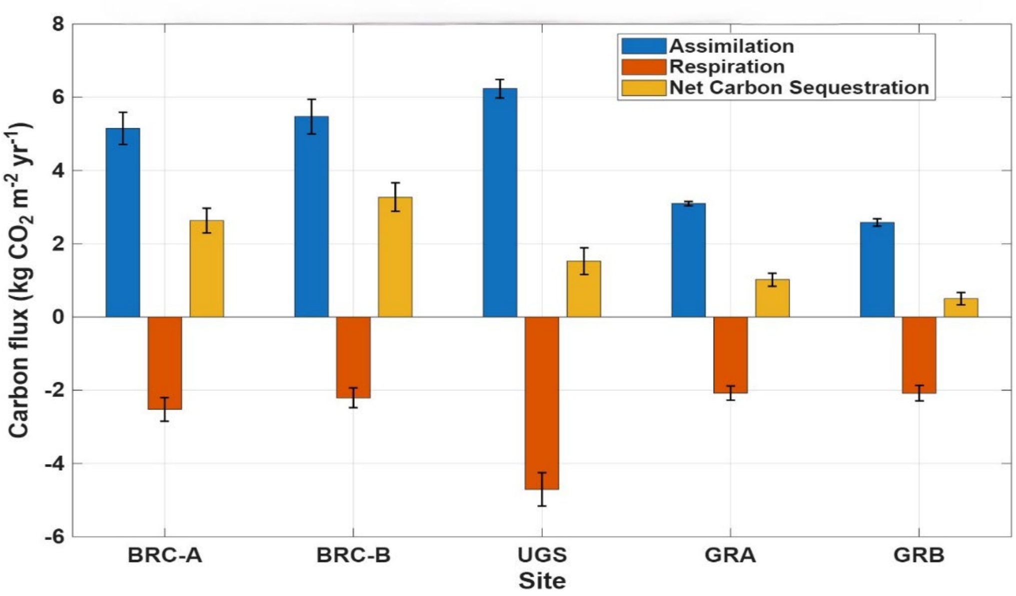


Figure 2. Estimated annual carbon sequestration components by site based on historical meteorological and soil data (2009-2018).

4 CONCLUSIONS AND NEXT STEPS

It is important to measure carbon fluxes on an annual basis to correctly estimate the carbon sequestration potential of BGI. This study shows that carbon sequestration drops during the dormancy period and under cold-temperature conditions, but that there is overall net annual carbon sequestration. Filter media thickness also affects sequestration potential, with lower potential observed in shallow green roofs. Starting in May 2026, the roof-water outlets were connected to the bioretention cells. Over the next two years, the effect of 50 times higher external water loading on the carbon sequestration potential of the bioretention cells will be evaluated.

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