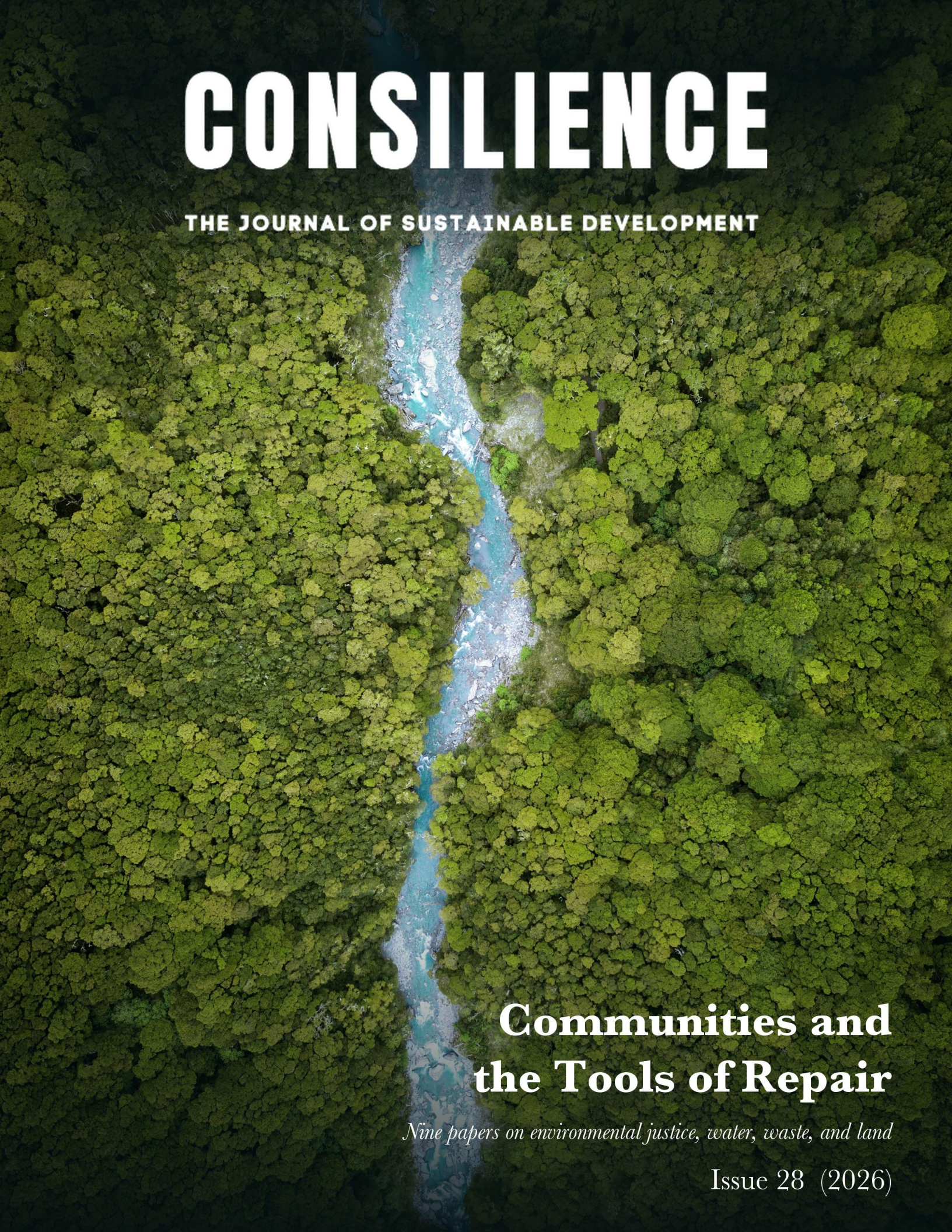

CONSILIENCE

THE JOURNAL OF SUSTAINABLE DEVELOPMENT

Communities and the Tools of Repair

Nine papers on environmental justice, water, waste, and land

Issue 28 (2026)

CONSILIENCE

THE JOURNAL OF SUSTAINABLE DEVELOPMENT

About the Journal

Consilience: The Journal of Sustainable Development is an online journal dedicated to promoting dialogue on sustainable development by bringing students, researchers, professors, and practitioners from a variety of disciplines and geographical regions in direct conversation with each other through an online, academically rigorous medium. As a multidisciplinary academic journal, our name is inspired by American biologist E.O. Wilson's eponymous text, which proposes ways in which to unite the sciences with the humanities.

Consilience publishes a range of academic material including scholarly articles, opinion pieces, field notes, and photo essays. By providing a public platform for discussion, we hope to encourage a global community to think more broadly, thoroughly, and analytically about sustainable development. The journal is run by a team of undergraduate and graduate students, under the guidance of faculty from Columbia University in the City of New York.

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CONSILIENCE

THE JOURNAL OF SUSTAINABLE DEVELOPMENT

Letter from the Editor-in-Chief

Dear Readers,

It is my pleasure to share Issue Twenty-Eight of Consilience: The Journal of Sustainable Development. The nine papers collected here write from particular places: a South Bronx neighborhood organizing against the air it was zoned into, flood-prone blocks of Chicago and Mumbai, a Tanzanian town rethinking its waste, the Mongolian countryside after socialism. Alongside them, our authors weigh the tools of repair, from debt-for-nature swaps to tree-planting campaigns that can degrade the very soils they promise to restore.

Reading these papers together, I am struck by how consistently they refuse easy answers. The most rigorous work in sustainable development does not announce solutions; it measures, listens, and reports what it finds, including the failures. That discipline is what we ask of every author who publishes with us, and this issue's contributors, whose work spans four continents and every stage of academic life, have met it.

My thanks go to our editorial team for the care they brought to every manuscript, and to our authors for trusting us with their work. Thanks as well to Columbia University Libraries, our publishing partner, for sustaining the infrastructure that keeps this journal freely available to readers everywhere.

It is a fitting picture of sustainable development as this journal understands it: local, empirical, and unfinished. We hope you read it that way, and that something in these pages stays with you.

Sincerely,

Param Sampat

Editor-in-Chief, Consilience: The Journal of Sustainable Development

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THE JOURNAL OF SUSTAINABLE DEVELOPMENT

Masthead

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Consilience: The Journal of Sustainable Development

Issue 28 • 2026

Published in partnership with Columbia University Libraries

535 West 114th St., New York, NY 10027

Distributed through Columbia University's Academic Commons

eISSN 1948-3074

Cover photograph by Will Turner, via Unsplash.

CONSILIENCE

THE JOURNAL OF SUSTAINABLE DEVELOPMENT

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CONSILIENCE

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How Environmental Racism Prevails: a Case Study Of Asthma Alley

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Abstract

Asthma Alley may sound like a fictional setting in apocalyptic literature, yet it is the unofficial name of a neighborhood in the Bronx, New York. This essay examines the history of environmental racism in Mott Haven, Bronx, and the emergence of South Bronx Unite– a climate justice movement formed in response to the polluted air of Asthma Alley. For almost a century, the South Bronx has been systematically neglected, exploited, and tarnished. The legacies of redlining, urban planning and rapid industrialization continue to perpetuate the environmental health crisis in the present. This essay contributes to literatures on environmental justice which address systemic racism and its intersections with public health. By focusing on the hyper-localized case study of Mott Haven through empirical evidence and an analysis of grassroots advocacy, I argue, we can better understand how systems contribute to maintaining environmental injustice. The work of South Bronx Unite in challenging existing policy frameworks which perpetuate the Asthma Alley crisis illuminates that environmental racism is not a modern phenomenon, but rather is a result of systemic racism and neglect embedded into our institutions. Lastly, it aims to bridge the gap between academic theory, public policy, and community action within current environmental justice literature.

Author's Note

This paper aims to deconstruct the policy manifestations of environmental racism in a case study of "Asthma Alley", by highlighting the systemic contributions of economic and urban development to public health disparities. Through an analysis of South Bronx Unite's activism and legal battles, this study develops how current policy frameworks, such as New York's SEQRA laws, continue to perpetuate environmental racism in marginalized communities. By situating this case within the broader discourse of urban policy, this research highlights the necessity of historical policy analysis to address gaps within current environmental and developmental legislation. Further analysis of the limitations of grassroots advocacy in overcoming systemic marginalization should be a key component of informing policy gaps and consequentially, reforms.

Keywords: Environmental racism, Marginalization, Redlining, Urban renewal, Environmental justice, Economic development

The Marginalization of the Bronx/ Historical Background

Redlining and Segregation

The roots of the environmental racism prevalent in Mott Haven can be traced back to the Great Depression. The extensive bank foreclosures of family homes prompted President Roosevelt to pass the National Housing Act of 1934, marking the birth of the Federal Housing Administration (FHA), which was created to provide mortgage insurance to family homes. In 1935, the FHA asked the Home Owners' Loan Corporation (HOLC) to create "Residential Security Maps" of 239 cities, ranking neighborhoods from A to D, with A being the most desirable (and least risky) and D being the most undesirable (and most risky). The FHA's underwriting manuals criteria required the use of racial covenants to determine the value of new housing and access to home loans. Neighborhoods with black or latino populations were categorized as high-risk investments, even if the homes were well-maintained or the area had a stable economy (Jackson, 1980). The FHA characterized communities of color as "infiltration"'s and "adverse influences" (Federal Housing Administration, 1938). These racist policies led to neighborhoods with as little as a 5-10% Black or Puerto Rican populations classified as type D (Ndiaye, 2020). This is known today as redlining, or the racial segregation of neighborhoods in the United States (Federal Housing Administration, 1938). Redlined/D-graded areas saw a distinct increase in African American and people of color populations compared to neighboring C-graded areas over the 20th century– a direct representation of the segregation that ensued (Aaronson et al., 2021). Moreover, the FHA's appraisal manuals advised banks to avoid lending in neighborhoods with "inharmonious racial groups", leading to chronic disinvestment and a plethora of socioeconomic problems related to poverty (Aalbers, 2007). The Residential Security Maps became the blueprint for urban and suburban planning, as they were used as guidelines to reconstruct American neighborhoods post-Great Depression. This planted the seeds for current-day environmental and health disparities, with research widely establishing that previously redlined neighborhoods are highly correlated with disproportionate levels of climate-related health risks (Swope et al., 2022).

Urban Renewal & White Flight

This segregation, both racial and mapped, led to the chronic disinvestment, neglect, and decline of neighborhoods like Mott Haven, as they were essentially deemed negligible. Redlining denied Black and Latino residents access to homeownership, while white families relocated to suburban areas through federal housing loans, a phenomenon known as white flight (Gibbons, 2024). The Bronx became even more of a haven for black and brown families in the mid-late 1900's, as a result of urban renewal policies (also known as 'Negro Removal') which demolished and gentrified urban neighborhoods in 'plight'(Sze, 2007). These policies displaced thousands of black and brown families, pushing them into redlined neighborhoods such as the Bronx: "In 1960, 50 percent of the [Bronx's] population was white, 10 percent black, and 40 percent Puerto Rican. By 1970, the black and Puerto Rican population was over 90 percent" (Sze, 2007). During this time the South Bronx became dangerously overcrowded, with it becoming common practice for landlords

to section single apartments for multiple families. By the 1960s the South Bronx became a literal dumpster for NYC, where blocks were cleared and NYC's waste was dumped- influenced by redlining zoning laws. In 1968 alone, fires in the South Bronx had increased by 50% (Muniz, 2024). The city took no action; in fact NYC was heading towards bankruptcy. Instead, NYC closed six fire companies in the South Bronx, and defunded many more– while simultaneously adding fire companies to a whiter and richer North Bronx (Zimmerman, 2011). By the 1980s, 80% of the housing in the South Bronx was destroyed, and over a quarter million people were displaced (PIX11 News, 2019). This came to be known as the Decade of Fire- one of the most drastic environmental racism terrors the South Bronx has endured at the hands of systemic neglect. This destruction perpetuated by a lack of funding, resources and infrastructure effectively turned the South Bronx into a large and dangerous slum, giving the Bronx the reputation that has lasted decades: dangerous, dirty, poverty stricken and crime ridden.

The Role of Urban Planning

As the South Bronx experienced the lasting plight of redlining, so did Mott Haven– through the means of urban planning. From 1934 to 1960 Robert Moses assumed the position of Commissioner of the New York City Department of Parks and Recreation and Chairman of the New York States Council of Parks (Sarachan, 2013). Despite building the New York we know today, Robert Moses earned a reputation of controversy through his career, being known to disregard perpetual public opposition to his work (Chronopoulos, 2013). Moses created numerous public authorities without ever being elected and controlled millions of dollars to fund ventures with little to no oversight. Uncoincidentally, redlined communities of color, such as Mott Haven, bore the brunt of this work. Mott Haven is encircled by the city's most concentrated network, including the Bruckner Expressway, the Sheridan Expressway, the Cross-Bronx Expressway, the Major Deegan Expressway, the Willis Avenue bridge and the Third Avenue bridge (Sze, 2007). During the construction of these highways in the 1960s, thousands of Bronx communities were destroyed, displaced, and divided (Resisting Displacement in the Southwest Bronx: Lessons from CASA's Tenant Organizing, 2017). Worse, these highways and bridges channel pollution via the highest concentrated network of diesel truck traffic in New York, laying the groundwork for the disproportionate asthma rates that would soon emerge (Butini, 2018).

This long history of racialized discriminatory policies and, consequently, governmental neglect and disinvestment set the stage for what we see today in communities like Mott Haven- disproportionately impacted by public health crises. The roots of environmental racism can be traced directly to governmental agencies and individuals in power who saw and treated Black and Latino communities as expendable, less-than, and unimportant. *As redlining disempowered communities of color such as Mott Haven, it seemingly gave a green light to policymakers to exploit and force the burden of whiter, affluent communities onto redlined ones*. Today this manifests as *Asthma* Alley

Industrial Concentration In Asthma Alley

In order to truly understand the magnitude of environmental racism in Mott Haven, it is necessary to delve into the history of the Harlem River Yard. The Harlem River Yard (The Yard) is a 106-acre industrial facility on the southern waterfront of Mott Haven. Bought by the New York State Department of Transportation (DOT) in 1982, The Yard was leased to a private developer, the Harlem River Yard Ventures Inc. (HRYV), for 99 years in 1999. The HRYV's proposed use for The Yard was approved after an Final Environmental Impact Statement by a HRYV consultant concluded that "trucks and other sources of air emissions associated with all the uses set forth in HRYV's land use plan would not have any significant adverse effect on air quality in the Bronx" (South Bronx Clean Air Coalition v. New York State Department of Transportation, 1995). Yet today The Yard is home to bus depots, tracker trailer distribution centers, numerous waste facilities, peak power plants, oil and fossil fuel facilities, a sewage-treatment plant and truck traffic from some of the busiest wholesale produce, meat and fish markets in the world. An interactive map provided by South Bronx Unite, a grassroots non-profit advocating for environmental justice in the South Bronx, shows polluting facilities along the South Bronx waterfront. Mott Haven, outlined in red, is disproportionately saturated with such facilities (orange). Though the Bronx's garbage is no longer dumped on city blocks in the South Bronx, the borough's waste transfer facility was placed in the most polluted and poor county of the city. Moreover, this high density industrialization of Mott Haven stands extremely disproportionate to NYC's median. While New York City-wide industrial land use is at a mere 3.5 percent, 21.6 percent of Mott Haven's land is used for industry (*NYC Community District Profile*, n.d. & *NYC Planning ZoLa*, 2025). Respectively, the Black and Latino populations NYC-wide and within Mott Haven are 51.5 percent versus 96.6 percent (Demographic Profile -New York City Community Districts 2000 Census SF1 Bronx Community District 1, n.d.). It is not only industrial zoning which disproportionately affects Mott Haven residents, but also waterfront access. Before the 1950s period of urban planning, South Bronx residents enjoyed waterfront access to the Harlem River, fostering a vibrant riverside economy. At this point two thirds of the Bronx's population was White (Gonzalez, 2004). This waterfront access ended with the construction of the Major Deegan Expressway in 1956 (Rolston, 2012). By the end of the expressways construction, in 1960, two thirds of the Bronx was Black and Hispanic (Gonzalez, 2004). Today, along the entirety of the South Bronx, there are only two points of waterfront access- one of which is privately owned (NYC Waterfront Access Map, 2025). On the other hand, the entirety of lower Manhattan (with an exception of 5 blocks below 23rd street), has public waterfront access (NYC Waterfront Access Map, 2025). These drastic disparities portray how the early legacy

of governmental policies and city planning persisted over a century to curate one of New York City's most marginalized communities.

To contextualize the impacts of the highways and industries that encircle Mott Haven on the health of residents, it's important to note that "more than 1.8 million children per year worldwide develop asthma due to exposure to nitrogen dioxide (NO2), a traffic-related air pollutant" (Environmental Defense Fund, 2024). Moreover, freight trucks and buses account for half of transportation related nitrogen-oxide emissions. Mott Haven's waterfront, The Yard, is polluted by industrial factories with large trucking operations. Just one, Fresh Direct, places 2,000 trucks going in and out of Mott Haven daily. Mott Haven, encircled by highways, has the highest pediatric asthma hospitalization rate in New York City—502.7 per 10,000 children, compared to just 22.4 in Bayside-Little Neck (NYC Department of Health, 2021). Another study, which placed air pollution monitors on a group of school children with asthma in Mott Haven and other parts of the South Bronx, found that these children were exposed to abnormally high levels of air pollutants, and were twice as likely to attend a school near a highway compared to children from other parts of the city (Goodnough, 2006). In fact, soot from truck's diesel exhaust had the worst effects on the children's asthma. The effects of this pollution is far reaching, with children in the South Bronx missing school for asthma-related complications 25 percent more than children in other neighborhoods (A Special Report on Asthma from the New York State Assembly, n.d.). For a child in Mott Haven, an simple asthma attack places heavy burden on families, as many parents/guardians can't afford to call out of work, much less afford extensive hospital bills, given that almost 50 percent of Mott Haven Residents live below the poverty line (South Bronx Unite, n.d.). The public health impact of this pollution was not a sudden development. It developed over time as the problem compounded from redlining, to urban renewal, to urban planning and disinvestment, resulting in the escalating environmental and health crisis which exists today.

South Bronx Unite

Despite decades of environmental health hardships, residents of the South Bronx community have fought back against the systemic neglect and pollution. The efforts of South Bronx Unite (SBU), a grassroots environmental conservation organization, have focused on protecting the social, environmental and economic future of Mott Haven and Port Morris. Founded in 2012, SBU emerged in response to the announcement of a deal between New York City and Fresh Direct- a grocery delivery service. Within the terms of the deal, the city offered Fresh Direct a $120

million subsidy, under the premise that the company relocate its warehouse to The Yard (Bronx Borough President, 2012). The deal was intended to keep Fresh Direct in New York, beating out a $100 million offer from New Jersey, after Fresh Direct announced its decision to relocate from Long Island City. The proposed move would add roughly 2,000 trucks moving in and out of the Mott Haven area daily (Weinberger, n.d.). The chosen site already housed a FedEx hub, *The New York Post* printing and distribution center, and a 5,000-ton-per-day waste transfer station- making the relocation of another pollutant heavy industry a major health concern. Fresh Direct's relocation to The Yard exemplifies historical patterns of environmental racism, in this case, industrial zoning in marginalized neighborhoods.

SBU was founded by neighborhood residents, community leaders and organizations that came together to recognize and oppose what they recognized as corporate disregard which would further devastate the health and quality of their community. Initially named South Bronx Unite Stop Fresh Direct!, the group originated as outraged residents and groups organizing protests and demonstrations against the initial plan. They demanded for the New York Industrial Development Agency (IDA) to block the deal using their vote in the decision making process- according to city law, any proposed industrial development must be approved by the IDA. Prior to the vote, Bronx Borough President Ruben Diaz Jr., the Bronx Overall Economic Development Corporation and Fresh Direct reached a "memorandum of understanding", a verbal agreement addressing community concerns (Alexander et al., n.d.). It asserted that FreshDirect would serve new Bronx neighborhoods, accept EBT benefits, and decrease the company's reliance on fossil fuels via purchasing 'green' vehicles. The South Bronx, which has some of the highest unemployment rates in the city, saw no gains from the relocation. What FreshDirect did was promise to create 1,000 jobs over 10 years, and out of those, only 30 percent of them would be for South Bronx residents- maybe. That is only 300 jobs for a community with a 46.2 percent unemployment rate and 36.3 percent poverty rate (The South Bronx: An Economic Snapshot, 2023 and Explore Census Data, n.d.). Moreover, Fresh Direct did not offer its services to over 90 percent of the Bronx, including the South Bronx (Wisnieski, 2012). It only delivered to wealthier, northwestern Riverdale and Kingsbridge sections of the Bronx. However, none of these agreements were on paper, for they were nothing more than an understanding. South Bronx Unite contested that the deal with Fresh Direct was non-binding, meaning that if Fresh Direct did not deliver on its promises, it would not face penalties. On the day of the vote, locals and organizers rallied outside the Industrial Development Agency's headquarters. However, their efforts fell through, as the deal passed with an overwhelming majority.

Nonetheless, South Bronx Unite continued to oppose Fresh Direct's relocation. Members turned to social media, posters, and word of mouth to continue to rally support, raise awareness, and gain as much media attention as possible. A simple google search of "stop Fresh Direct" will provide dozens of articles and media sources covering the devastating environmental and health impacts of the move, most of which reference South Bronx Unite. Locals continued to voice their concerns and grievances. As community board member Mychal Johnson asserted, "The South Bronx is the poorest congressional district in the nation, continuously dumped on with all the worst New York City has to offer" (Alternet.org, 2012). Residents had their

problems ignored while the city continued to shower cash on corporations, a long standing struggle of governmental neglect that the South Bronx is familiar with (South Bronx Clean Air Coalition v. New York State Department of Transportation, 1995). South Bronx Unite soon turned to other methods to contest the relocation of Fresh Direct. In a last attempt to demonstrate collective community disapproval of the development, SBU organized for a citywide boycott of Fresh Direct, launching boycottfreshdirect.com, a website no longer available. Then, they sued. This paper will now explore the methods of South Bronx Unite's struggle against the relocation of Fresh Direct to highlight existing institutional frameworks allowing for environmental racism to continue to be perpetuated despite existing environmental justice frameworks.

Lawsuit

On June 18, 2012, South Bronx Unite (SBU) filed a lawsuit against several city entities, including the New York City Industrial Development Agency (IDA), the New York State Department of Transportation (DOT), and Harlem River Yard Ventures, Inc. The lawsuit was filed under three premises. First, the lawsuit contended that the NYC Industrial Development Agency failed to conduct an adequate environmental review of Fresh Direct under the New York State Environmental Quality Review Act (SEQRA), specifically section 8-0113(1) (South Bronx Unite! V. New York City Industrial Development Agency, 2014). This provision of SERQA requires Environmental Impact Statements (EIS) for "determining whether or not a proposed action may have a significant effect on the environment, taking into account social and economic factors to be considered in determining the significance of an environmental effect, including whether it may cause or increase a disproportionate pollution burden on a disadvantaged community" (SEQRA, Environmental Conservation Law § 8-0113(1)). The legal basis of this rests on the principle of environmental justice law, meant to prevent discriminatory practices which expose marginalized communities to harmful environmental conditions. This is a key legal framework where environmental racism can be legally challenged.

In 1993, the Dept. of Transportation (DOT) conducted and submitted an Frinal Environmental Impact Statements (1993 FEIS) of the Harlem River Yard Ventures' (HRYV) Land Use Plan for The Yard. However, in 2012, when FreshDirect was proposed to move to The Yard, Fresh Direct commissioned a private environmental impact review. Based on this review, the Industrial Development Agency issued what is known as a "Negative Declaration", which asserts that if a proposed project would have no significant negative impacts, it avoids the need for a new EIS. This Negative Declaration allowed the IDA to rely on the findings of the 1993 FEIS. South Bronx Unite's lawsuit sought to annul the negative declaration under the premises that the 19 year old 1993 FEIS was drastically outdated on accounts of rezoning, the influx of new residents, and didn't account for the city's (then) current approved plans for The Yard. Moreover, SBU stipulated that the IDA's classification of Fresh Direct as a "minor modification" failed to account for the impacts of greenhouse gas emissions, which were not adequately addressed in the 1993 FEIS (South Bronx Unite! V. New York City Industrial Development Agency, 2014). Therefore, SBU sought to annul the negative declaration and compel the IDA to

conduct a new EIS, or at very least, a supplementary EIS to properly assess the environmental impacts of Fresh Directs relocation.

The second part of the lawsuit concerns the original lease of the Harlem River Yard to HRYV by the DOT. In the original lease contract (provide a date), 28 acres of The Yard were to be set aside for an intermodal rail terminal. This intermodal rail hub was intended to reduce truck traffic and pollution in Mott Haven by serving the transportation needs of the industries within The Yard. However, by 2012, it had still not been built. SBU contended that the relocation of Fresh Direct encroaches on the reserved land, thus rendering its move to be in violation of the contract. Lastly, the third and final cause of action argued that Fresh Direct's acceptance into the New York Excelsior Jobs program, which provided it $19 million in tax credits, was illegal (South Bronx Unite! V. New York City Industrial Development Agency, 2014). The New York Excelsior Jobs program was created to support industries such as "clean-tech, broadband, informational systems, renewable energy and biotechnology." According to the statue by which the program was created, certain types of businesses were explicitly excluded from receiving tax credit. Specifically, businesses engaged in "predominantly in the retail or entertainment industry" were excluded from the program (Empire State Development, 2017). A google search of "is fresh direct a retail business" will provide that the Empire State Development Corporation overstepped its boundaries by admitting Fresh Direct into the New York Excelsior Jobs program. Thereby, SBU seeked to invalidate Fresh Direct's acceptance into the program.

On May 24, 2014 the Bronx Supreme Court dismissed the lawsuit brought by South Bronx Unite, and FreshDirect was cleared to relocate to the Harlem River Yard. The court dismissed SBU's request for a new Environmental Impact Statement on the premise that Fresh Direct's commissioned review sufficiently showed that no significant environmental harm would occur . SBU's claim that FreshDirect would interfere with the intermodal terminal was dismissed due to the fact that the statute of limitations for the suit had passed. Statute of limitations refers to the legal time limit within which an entity can bring legal action. Lastly, SBU's efforts to remove Fresh Direct from New York Excelsior Jobs program was dismissed as SBU failed to name a specific officer or employee of the state responsible for illegally accepting Fresh Direct into the program. In 2014, South Bronx Unite attempted to appeal the dismissal of their lawsuit in 2013, but the appeal was unsuccessful as the court upheld the decision to not require a supplemental Environmental Impact Statement (South Bronx Unite! V. New York City Industrial Development Agency, 2014). Fresh Direct moved forward with its plans to relocate, opening in 2018.

Policy Implications

Unfortunately, the court's firm claim that the communities surrounding FreshDirect would not experience significant environmental harm would quickly be proven false. In the years following their defeat in court, South Bronx Unite partnered with Columbia University to conduct a study on the truck and vehicle flow impacts on air quality, from June 2017 to May 2020- before and after the opening of Fresh Direct's facility. The study showed a significant increase in diesel truck and vehicle traffic,

especially overnight, with the overall traffic increase being between 10 and 40 percent (Grocery Depot Brings Increased Traffic to the South Bronx, 2020). Moreover, the research showed an increase of 0.003 μg/m3 in black carbon air pollution after Fresh Direct's move (Grocery Depot Brings Increased Traffic to the South Bronx, 2020). This seemingly miniscule increase in pollution is consequential, as even the smallest increases of pollution in neighborhoods with poor air quality can tangibly exacerbate health consequences for residents (Grocery Depot Brings Increased Traffic to the South Bronx, 2020) .

This measured polluting consequences of Fresh Direct's move to The Yard directly refutes the Bronx Supreme Court's claim that Fresh Direct's independent review sufficiently showed no significant harm would occur. The disproportionate environmental degradation and consequential health risks in Mott Haven had been well documented and established prior to the announcement of Fresh Direct's relocation (Sze, 2007). Moreover, the significant impact of diesel vehicles on such degradation had been widely proven, through the history of urban planning, research, and even hospitalization rates. Nonetheless, Mott Haven saw a prioritization of economic development over public health and quality of life once again. However, the plight of South Bronx Unite's efforts highlighted the specific legal and institutional frameworks preventing environmental justice from succeeding. In this sense, the failure of SBU's efforts provides us with the ability to pinpoint the exact measures needed to protect communities of color from further marginalization and neglect. Next, this paper will discuss these key frameworks and patterns within them, in the case of SBU's efforts, and then within the context of broader environmental racism crises.

SEQRA Frameworks

The dismissal of South Bronx Unite's request to conduct a new Environmental Impact Statement highlights a longstanding history of disregarding the public concerns of marginalized communities. Economic development has historically and systemically been prioritized over the livelihood of communities of color, such that inequalities grow proportionally to urban growth and development(Nicoletti et al., 2022). To start with, the governmental framework to allow and rely on the findings of corporate-funded (essentially) self-evaluations is inherently flawed, as seen by the case of Fresh Direct. Section 8-0105 of SEQRA stipulates that the Industrial Development Agency may require an applicant to submit an environmental report to aid the agency in determining if an Environmental Impact Statement is needed. Fresh Direct's self-funded findings proved (by Columbia University's study) to downplay the severity of the situation- as is often the case with corporate ventures (Margolis & Walsh, 2003).

Moreover, the lawsuit's dismissal of conducting an Environmental Impact Statement, highlights the ineffectiveness of such systems meant to protect at-risk communities. The premise on which the suit was dismissed was that Fresh Direct's independent review did not indicate significant environmental damage. Yet according to New York State law, such reports are only meant to "assist" the Industrial Development Agency IDA's findings, which must be "their own independent judgement". Given that this judgement was solely based on Fresh Direct's review, it is

accurate to conclude that the independent review determined, not assisted, Industrial Development Agency's findings. This goes to say that even when environmental/social justice laws do provide rather 'rigid' instructions within legislation, they aren't strictly followed in the face of corporate interests. By allowing Fresh Direct to relocate without an Environmental Impact Statement, the credible public concerns about health and environmental justice- which such laws are meant to validate- were treated as expendable by the Industrial Development Agency. The Industrial Development Agency was founded to promote economic development- a principle that has historically taken precedence over the autonomy of communities of color such as Mott Haven (Margolis & Walsh, 2003). By having entities that are founded upon the principles which have caused harm to marginalized communities, to in turn protect them, creates systems that are intrinsically contradictory and ineffective. It does not come as a surprise that an economic agency dismissed valid community concerns at the word of a corporation, circumventing proper enforcement of the SEQRA laws it is bound by. Though in the past couple decades America has seen an influx of restorative justice policies and systems, the validity, credibility, and effectiveness of them is questionable. This case of Fresh Direct exposes such systems to be simply performative in nature: asserting a commitment to environmental justice while allowing for the same patterns of harm to persist.

Here, three main flaws within NYS's SEQRA laws are presented: allowing for corporate self-evaluations, lack of proper enforcement, and enforcement by an economic agency.

Bureaucratic Frameworks

A clearer form of institutional neglect is seen in the legal framework of the court's dismissal of removing Fresh Direct from the New York Excelsior Jobs Program. In the court's Amicus Curiae brief, the judge stipulated that under state finance law, SBU needed to name a specific individual(s) responsible and clearly trace the state's improper expenditures. Here, the nuances of bureaucracy were used to avoid government accountability. By preventing marginalized communities from holding decision-makers accountable, the ruling highlights a critical flaw. This verdict legally renders substantiated claims and concerns irrelevant, in effect facilitating environmental racism. In the case of Mott Haven, such nuances contributed to the health disparities that resulted in disproportionate death rates during the COVID-19 pandemic (New York State Comptroller , 2023).

Policy Standards

The initial decision to relocate Fresh Direct to The Yard also highlights faults in our current policy standards. The inability of strong, local, organized opposition to block the initial relocation decision is a testament to the lack of public voice and accountability in the SEQRA and land use planning process. A recurring theme highlighted throughout this movement was the lack of accessibility community members had to the politics that were shaping their lives. SBU and many other critics of the deal spoke out about its lack of transparency, but more importantly, its lack of democratic process. No elected official had a vote on the $120 million subsidy deal,

nor did local community boards hear of the deal until it was announced (Brooklynites Share Development Fight Lessons with Boogie down Brethren, 2012). Moreover, the only public meeting that did occur was two days after the proposal was announced, and in the Financial District- a district with the highest income rates in NYC, and one an hour away from Mott Haven (Alternet.org, 2012). Tactics to keep marginalized communities uninformed of harmful agendas have a long history in aiding environmental racism crises (Sze, 2007). Evenmore, when locals and community activists strongly voiced their opposition to the relocation of Fresh Direct, the government's response was strongly aimed towards appeasing community concerns instead of reciprocating and addressing them. The 'memorandum of understanding', brought by the then Bronx Borough President, reached agreements with Fresh Direct regarding environmental, job, and accessibility concerns prior to its relocation. The last clause within this agreement pertains to the details of liability if the agreements are not met: "No officer, agent, or employee of any of the parties hereto shall be charged with any liability" (Bronx Borough President, 2012). By listening to the concerns of community members and then announcing that an understanding was reached between the government (on behalf of the community) and Fresh Direct, Bronx Borough President Diaz misled that these concerns would be met. However, they were not– at most they were simply relayed. For instance, one of the many 'agreements' made by Fresh Direct was a 5-year plan to convert to a fully electric fleet of trucks. Today, 12 years later, Fresh Direct's fleet still utilizes diesel fuel(Campaign against Fresh Direct, n.d.). Public agreements like the memorandum of understanding are only effective in deceiving the public and/or dismissing their concerns. Ensuring that public opinion is voiced in policy making is a fundamental tenet of American politics, and its importance is only furthered by the fact that Fresh Direct's relocation was funded by taxpayer dollars. Essentially, residents of Mott Haven were forced to pay for an industry which they widely opposed. This case emphasizes institutional patterns dating back to redlining: a lack of transparency, access, and acknowledgement of concerns.

Implications

These systemic frameworks highlight the need to deconstruct and analyze current policies in order to implement reforms which are actually effective. This case study effectively pinpoints systemic frameworks in New York that continue to perpetuate the Asthma Alley crisis. Currently, the New York State Department of Environmental Conservation (DEC) is responsible for the oversight of SEQRA laws, while implementation is handled by local agencies. First, this research calls for SEQRA laws to ensure that the environmental review process is solely conducted by an agency dedicated to conservation measures (DEC), independent of conflicting goals (such as in the case of the IDA), instead of delegating responsibility to locally selected departments. Moreover, it demonstrates the need for a more rigid EIS conduction process- one that does not hold place for self-funded corporate reviews. While current SEQRA laws encourage public participation in the EIS process, this case study demonstrates the lack of effectiveness in this commitment and asserts that the legislation must require a vote before a development is approved, which includes a local governmental body (community boards) and at least one locally elected official. Second, it recognizes the ability of bureaucratic nuances to circumvent government

accountability and calls for reform of such bureaucratic frameworks when pertaining to high risk policy. Lastly, this research calls for an independent (government contracted) agency specific to handling public participation in SEQRA laws, such that the public is effectively provided notice of proposed developments, public hearings are adequately accessible, and public comments and concerns are documented, ensuring engagement and transparency throughout the whole process.

Conclusion

This paper is a critical, detailed examination of how environmental justice movements struggle not because of a lack of merit but because of structural barriers embedded in governance and policy. This paper delves deep into the history and roots of environmental racism in Mott Haven, and shows how policy decisions made the neighborhood into what it classified it as- hazardous. The legacy of racism in communities like the South Bronx manifests in more ways than just one, creating- health, socioeconomic, civil liberty- barriers to the livelihood of communities of color. In order to dismantle these barriers, the full scope of how our institutions have adopted them must be better understood. This research zooms into environmental racism- establishing that environmental justice policy must be bulletproof in order to protect lives.

South Bronx Unite's struggle against Fresh Direct illustrates the ongoing environmental racism in Mott Haven and the (some of the) varying systems of institutional neglect which perpetuate it. From its foundation, South Bronx Unite's efforts were hindered by seemingly invisible systems which revealed themselves as the marginalization of Mott Haven was threatened and tested. These failures specific to SBU highlight broader trends of governmental neglect in communities of color. From performative environmental justice laws to governmental lack of transparency- recognizing and analyzing the systems which hinder justice movements is crucial to dismantling them. There are clear patterns within such ineffective and harmful systems that are crucial to recognize in order to safeguard our communities. South Bronx Unite's efforts revealed a large network of discriminatory policies which inhibited its original goal. These issues highlight a broader crisis: not all Americans are fairly represented in the policy-making process. This is well documented in academic literature, where the policy-making is disproportionately responsive to the preferences of socioeconomically affluent constituents and businesses (Inequality and American Democracy, 2025). This results in whiter, more affluent communities, having a more effective voice in policy than disadvantaged communities. This is exemplified through the bureaucratic nuances used to dismiss government accountability in SBU's suit, the lack of government transparency surrounding Fresh Direct's relocation and Borough President Diaz's memorandum of understanding. This paper's proposed solutions- public stake (vote) in the decision making process, an independent agency tasked with public engagement, elimination of corporate self evaluations, and enforcement by means of the DEC- allow for marginalized communities to have a streamlined and tangible voice in the policies which impact them. The methodology of this paper– examining the failures of justice movements– precisely pinpoints systemic barriers to institutional reform. Moreover, this method to dismantle systemic failures can be employed among broader policy reform efforts. This study calls for a shift in the way

current literature examines institutional failures, and in turn, reforming the way policy is informed by academics. Lastly, it calls for citizens to recognize the patterns which often accompany and aid governmental neglect, namely, an institutional lack of transparency, access and acknowledgement of concerns.

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Consilience: The Journal of Sustainable Development
Iss. 28 (2026)

CONSILIENCE

THE JOURNAL OF SUSTAINABLE DEVELOPMENT

The Toxic Legacy of Industry in Nova Scotia: The Environmental Violence of Sydney Steel

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Abstract

The steel mill in Sydney Nova Scotia and the associated tar ponds were a site of extreme environmental violence against the indigenous Mi'kmaq peoples who hunted and fished on the land before the mill was constructed and against the working-class people of Sydney who lived and worked in the pollution the mill produced. Using an environmental violence framework this paper analyzes scientific and historical data to make the case that the extremely slow reaction to the harm being done to these communities by the pollution produced by the mill was due to a disregard for their lives and their devaluation as people. The land and people were viewed as simple resources to be exploited, they were 'resourcified,' much to their detriment and thus they suffered as they were heavily contaminated with the byproducts of steelmaking. This pollution led to contamination throughout the food chain and water supply, leading to high rates of birth defects and cancer, an act of violence of a slower variety than we are used to. This disregard for human life is sorely underrepresented in scientific literature, and as such this paper aims to bridge the gap in the communication of what has happened in Sydney and raise awareness for the deeper reasons behind this and other similar environmental tragedies.

Author's Note

I wrote this paper because as a Nova Scotian, this issue is close to home for me. I care about the environment, and I care about people, and I want to advocate for both to be treated well and respectfully. When I see injustice being inflicted on people, I want to bring attention to it, and when we see the system failing, I do not think we should be quiet about it. If we remain silent, nothing will ever get fixed, so we must be loud. I think this paper is relevant to the field of sustainable development because we cannot just focus on fixing the physical problems in the pursuit of sustainability, we must fix the systemic ones too. We must ensure that the sustainable system we are building is fair and beneficial for everyone and not just those in the majority or who have money.

Keywords: Violence, Indigenous, Pollution, Politics

Introduction

Nova Scotia has a long history of environmental violence motivated by both race and class, and the Sydney Steel Mill is a prominent example in that history. Beginning operation in 1901 the Sydney Steel Mill and the associated Sydney Tar Ponds left an enduring mark on the local Mi'kmaq community through the destruction of one of their traditional hunting and fishing grounds, as well as leaving a destructive and enduring mark on the health of the people of the nearby city of Sydney (Waldron, 2021). This represents a devaluation of the environment, the Mi'kmaq peoples who called this place home before the colonists arrived, and who still do today, and the working-class community of Sydney. The following will be an analysis of the race- and class-based violence committed by the operators of the steel mill against the aforementioned people who relied on both the mill and the environment that it was polluting for their livelihoods. This treatment demonstrates a level of dehumanization and resourcification of these communities precisely of the form described by Cohen and Biro in their recent analysis of Canada's natural resource political economy, *Organizing Nature: Turning Canada's Ecosystems Into Resources* (Cohen & Biro, 2023). Environmental violence is an important issue in the history of not just Nova Scotia but industrialized society generally, and it does not receive enough attention in the mainstream discussions of the climate crisis. The practice followed by developed countries of offshoring their polluting heavy industry repeats the environmental injustice already inflicted on their own prior generations, only internationally on the future generations of other peoples. Developed countries offshoring pollution heavy industrial activity is a form of environmental violence against the host country just as much as doing it to a vulnerable domestic population is. This represents a system that is thoroughly, and repeatedly, destructive in its pursuit of profit, laying waste to both communities and environmental integrity on scales ranging from the most local to the global. The following analysis of one of Nova Scotia's most well-known cases of environmental injustice is an effort to illuminate the callous and destructive nature of the actions of government at local, provincial, and federal levels towards the vulnerable people it should have been doing the most to protect.

An analysis of the political motivations and implications of phenomena like Sydney Steel is important because it offers sociological, political, and cultural contexts for the data generated by the scientific investigations which often uncover the magnitude of environmental or human damage inflicted by environmental injustice. The data, though, is often lacking the "why" of the event, the political motivations behind it, and the broader social and cultural implications, encompassing everything from property values to cultural dislocation and health care costs. Many of the scientific sources I have cited in this paper are 'purely scientific' with very little analysis of why the event happened. Works such as Dodds and Seviour (2001), a purely scientific piece of work, and Haalboom et al. (2023) are superb factual discussions, but they offer little explanation of larger trends which influenced the situation. The same thing is true of Campbell (2002), as the work provides a sociological perspective on the course of events, discussing systemic failures and providing some analysis of why those failures occurred, concluding that financial considerations and systemic failures were primarily responsible for the severity of the situation at and around Sydney Steel. However, a discussion of the *origins* of those actions, and the thinking that drove them,

could have been developed further by Campbell. The motivations which led to the steel mill and its associated infrastructure being sited where it was, at a location of tremendous importance to the Mi'kmaq people, are little discussed beyond brief mention in works such the book *There's Something in the Water* by Ingrid Waldron (2018b) and a pair of shorter pieces also by Waldron (2018a; 2021) which discuss Sydney Steel as part of a broader and clearly-visible historical trend of racial bias in Nova Scotia's provincial environmental policy across many governments and multiple levels of administration. By the same token, the role of class is also little mentioned relative to environmental harms in works I have encountered beyond a mention by Campbell (2002) of the history of neglect facing traditionally working-class Cape Bretoners, but even that does little to tie in class issues as the drivers, partial or total, of the neglect in the first place. *Closing Sysco* by Mackinnon (2020a) provides the only significant work I came across tying class into this story, indeed the only significant work on Sydney steel at all. It focused in part on the working-class environmentalism of the mill's employees in later years as the harms became more publicly known, and more broadly on the rise and decline of industry in Cape Breton through the story of Sydney Steel and it's workers. Though a good study of the systemic oppression of the working-class at Sydney Steel as well as their concerns over hazardous working conditions and industrial pollution, this work only lightly touches on issues of race and does so mainly in relation to discriminatory and exclusionary hiring practices and the theft of land and resources from the Mi'kmaw, passing them over after brief mentions. This present analysis is my attempt to bridge that gap, to offer an answer to that question of "why" – what are the origins of the thinking that produced the decisions that were instrumental throughout the Sydney Steel story, from its inception in 1901 all the way to the present. It is just as important for us to discuss why decisions are made as it is to discuss their effects, and it is important that we communicate our findings broadly. Such knowledge is necessary for us to recognize, challenge, and ultimately dismantle the deeply unjust thinking which has informed and regrettably continues to inform the environmental policies of governments like that of Nova Scotia.

Theoretical Framework

Environmental violence as this paper approaches it is a form of slow violence, where the damage done to the environment then harms the people relying upon it (Marcantonio & Fuentes, 2023). The "slow" part of the violence is found in the slow but inexorable manifestation of the harms themselves, everything from incidence of cancer—particularly lung cancer, birth defects, and other health issues in humans, and the steady loss of biodiversity and pollution or destruction of ecological integrity (Campbell, 2002; Dodds & Seviour, 2001; Mackinnon , 2020a; Marcantonio & Fuentes, 2023; Waldron, 2018a). This violence is conceptualized using the framework developed by Marcantonio and Fuentes (2023) where "environmental violence [is] defined as direct and indirect harm experienced by humans due to toxic and non-toxic pollutants put into a local—and concurrently the global—ecosystem through human activities and processes" (Marcantonio & Fuentes, 2023, p. e861). This definition of environmental violence also makes room for and acknowledges the role of structural and cultural violence, comprising the power differentials and vulnerability that often

prevent the party being harmed from obtaining the justice they deserve. This framework also acknowledges the importance of a material vector of violence; something must be causing the harm. With this understanding of environmental violence, we can see room for both a racial and class-based forms of discrimination and their capacity, indeed their likelihood, to intertwine as represented by both structural and cultural violence, both of which will be explored in this paper through their impacts on the Mi'kmaq and the working-class people of Sydney. This paper also explores the idea of resourcification as discussed by Cohen and Biro (2023). Their argument is that when something, or someone, is viewed simply as a tool to be employed, an object to be exploited, or simply as a vector to add value, that person or thing has become resourcified. No longer seen for what they are but for what they can be used to produce or to provide, people, ecosystems, practices, or beliefs only hold the value – the utility – that the system attaches to them. In the case of the Sydney steel mill, we see this play out twice, as the environment is seen only as a resource base at the beginning of an industrial process, and as a dumping ground for the waste at its end. Mirroring this, the people of Sydney are only seen as producers of labor value and no longer as people whose lives were threatened by the pollution of their environment. When people, ecosystems, and the environment become resources, they become expendable, consumables reduced to statistics for the systems that encompass them: they become means to an end for others instead of an end in and of themselves. In short, the very systemic institutions and regulations which are stated to protect them and support them, instead exploit them and subsequently block their path to restitution and restorative justice.

The Damage Caused by the Mill

The environmental damage done to the area centers mainly on the creation of the Sydney Tar Ponds, an area of roughly 33 hectares contaminated with approximately 700,000 tons of pollutants including very high levels of arsenic, antimony, benzene, and xylene (Campbell, 2002). This massive contamination load has led to elevated cancer rates in the communities of Sydney and Whitney Pier, which encircle the Tar Ponds sites. In addition to these epidemiological effects, the aforementioned contaminants as well as many others leached into the surrounding environment, contaminating ground water sources and the vegetable gardens that working-class inhabitants relied upon for sustenance and income from sales (Waldron, 2021). This contamination of the environment and food sources has contributed to the unusual rates of cancer in Sydney, which are among the highest in Canada (Haalboom et al., 2023; Mackinnon, 2020; Waldron, 2021). Additionally, there is some evidence that the chemicals polluting local ecosystems have produced harmful effects on mothers giving birth in Sydney and Whitney Pier (Dodds & Seviour, 2001). The main and most significant effect found was an increase in congenital birth defects in Sydney of 25% compared to the rest of Nova Scotia, a rate of 2.8% compared with 2.3% across the rest of the province, a statistically significant increase not present in neighboring communities within the county (Dodds & Seviour, 2001). These are clear examples of slow environmental violence in action, generating impacts that develop over years or decades, and which persist for at least as long. Because of its slow pace, this phenomenon is rarely seen as a form of violence: actual harms may not be

immediately apparent, or those harms' pathways into peoples' lives – via the vegetables grown in their family gardens, for example – may be difficult to track. We therefore struggle to conceptualize the processes themselves as violence, associating it as we do with immediate pain and harm, not something long and drawn out. This violence is rendered even more significant when we consider that the provincial government knew at least as early as 1974 that the levels of polluting chemicals which had been intentionally dumped in the Tar Ponds were indisputably and significantly above their own safety requirements (Campbell, 2002). This represents not just a systemic failure to address an issue, but in failing to act upon this knowledge the government clearly committed an act of violence not only against the people who were already suffering the effects of these chemicals, but also against those who had yet to fall victim to their impacts. We cannot escape the conclusion that the government's failure to act was based, at least in part, on an assessment that the lives of the people – citizens of Nova Scotia – were less important, less valuable, than the steel produced by the mill. There is in recent history, a measure of positivity to be seen in the trajectory of this situation at least, as the Tar Ponds have finally been cleaned up and remediated as of 2014 however only time will tell how much that has done for what pollution has already seeped out into the surrounding environment and into local food resources (Waldron, 2021).

An Attack on the Mi'kmaq

There is an inherent degree of racism in the choice of location of the steel mill. Placing such a dangerous and destructive industry in the traditional and unceded hunting grounds of the local Mi'kmaq is hard to discount as being purely happenstance, especially since at the time the explicit policy of the Canadian state was the elimination of Indigenous cultures and their assimilation into European Canadian society (Government of Canada, 2010; 2017; 2023; Matheson et al., 2022; Taylor, 2020; Waldron, 2021). To that end, the destruction of the very landscapes they rely upon to maintain their way of life makes a lot of sense. If they have nowhere to hunt and fish and live as they wish according to their traditions, logic would dictate to Canada at the time at least, that they must see the Canadian way as better, and if not better, then as the only alternative. This is all rooted in the assumption of colonial culture that they hold a position of cultural superiority and that as such they have more right to do as they wish with the land than the native peoples. These native peoples were often regarded as not even being people as exemplified by ideas like the doctrine of *terra nullius*, which described the "New World" as open and uninhabited, ripe for settlement by European colonists (Cohen & Biro, 2023). Indeed, the Mi'kmaw faced discriminatory hiring practices, rarely finding work at the mill, alongside their exclusion from partaking in the wealth generated from the natural resources being harvested from their own land (Makinnon, 2020a). All of this comes from a devaluation of the Mi'kmaq and other Indigenous peoples who were seen as something to be remedied by the Canadian state and society, something we are still struggling to overcome even today (Taylor, 2020).

An Attack on the Working-Class

The working-class people of Sydney also faced significant environmental violence and in this issue I see an intersection of race with class which may have played some role but it is hard to say how much. Through much of the mill's life Sydney was a working-class city with a largely European-descended population, however Whitney Pier, which provided significant unskilled labor to the mill was and remains incredibly diverse, pulling from all over the world, and including a significant population of African descent (Beaton, 1995; Collections Canada, n.d.; Muise, 2013; Parks Canada, 2017; Statistics Canada, 2021). Despite the fact that the Canadian state knew of the pollution the mill was putting out in 1974 nothing was done about it for decades until 2004 and the health considerations came second to the economic output provided by the mill (Campbell, 2002; Muise, 2013; Waldron, 2021). The contamination itself is most densely concentrated in Whitney Pier, however the harms are dispersed widely across the city and when situated in the context of a history of violent working-class suppression in Sydney, it seems unlikely that there is purely a racial motivation to the neglect. Instead, the impact seems to be driven by a broad disregard for all of the working-class people of the Sydney area who's labour supported the mill (Haalboom et al., 2023; Lambert & Lane, 2004; Mackinnon, 2020b). The steel was still getting made and the people were being treated as a resource to be expended in its production, much in the way resourcification was discussed by Cohen and Biro (2023), the people themselves became the resource and they were seen mainly for what they produced and less as people who were suffering from the pollution that was being put out (Cohen & Biro, 2023). They were simply workers, regardless of race, and it wasn't worth fixing the issue for any of them because they were expendable and replaceable.

The Resourcification of Land and People

Resourcification is at play in two major ways in this case. The land was resourcified for the productive capacity that could be built on it and extracted from it, as well as for its ability to receive the pollution generated by those productive processes which, in turn, of course, would reduce its long-term value as a resource. The people of Sydney, on the other hand, were resourcified for their ability to process those resources and to produce value from them. From the system's perspective, this was their only inherent value. Anything beyond the land's resource value and people's productive capacity fell away and was deemed less important at best, and utterly unimportant at worst, as a signifier of value. The land could be polluted and destroyed because there was no negative cost preventing or even discouraging the behaviour. Because there was no cost, there was (and often remains) no system-wide sense of responsibility towards the victims of the environmental injustice of Sydney Steel, and therefore no clear path for them to achieve recognition, let alone restitution for the harms endured. (Campbell, 2002). The poor quality of the local coal used in the coking process as well as that of the resulting steel was irrelevant in any decisions concerning the mill's safety or environmental impact. Only when the mill's profitability was in decline in the late 1950s were efforts made to replace the local coal with American coal of a higher quality, and also to process foreign ore, but while the quality of the steel produced with cleaner coal increased, the cocktail of pollutants produced by the coking

and smelting processes continued to be dumped into the Tar Ponds and elsewhere on the mill's site, from where they leached into surrounding areas. Throughout the life of the mill, human lives became expendable and the very environment that they relied upon for survival, the very employer that many of them relied upon for their livelihood, became a hazard to their health. When their predicament became clear, when the harms inflicted were increasingly apparent, at that point they were repeatedly informed by the provincial government that there was nothing wrong with what was coming out of the steel mill. The very agencies of government supposedly established to support people, instead abandoned their responsibility to do so.

Conclusion and Recommendations

Environmental violence, as well as the resourcification of land and people came together in Sydney to create a perfect storm which had detrimental effects on the communities which surrounded the Tar Ponds and the mill site. The Mi'kmaq lost more land and a traditional hunting and fishing ground, and the people of Sydney and likely other nearby communities were poisoned by dangerous chemicals. For a good portion of this period, the provincial government was well aware of the danger. The issue of slow, violent, environmental injustice explored in the example of Sydney Steel is by no means unique to Nova Scotia: it is endemic across the vast country of Canada and needs to be further studied, especially in light of the rapidly accelerating effects of climate change which open an entirely new dimension to the phenomenon of environmental injustice (Waldron, 2018b). We must examine the thinking which underpinned the situation of industrial projects in Canada, and the balance that was struck between productive processes and the environmental and human impacts of those processes. These cases and more could, and should, be examined though the lens of environmental injustice as a slow-violence phenomenon and if I must recommend any way to go forward, I think we need to take a much deeper look at where industrial projects are built in Canada and further explore how and why they end up where they do. It cannot be ignored that Sydney is not an isolated example, and it needs to be examined as simply one manifestation of a wider epidemic of systemic environmental violence against vulnerable communities in Canada. Greater study and communication are required not just on the physical harm caused by cases such as Sydney, but for the political implications of their very existence. The lack of care exhibited by the systemic forces – economic, political, racial – towards both the working-class people of Sydney and the Mi'kmaq who originally inhabited the land is a prime example of the destructive nature of the Canadian colonial project built overwhelmingly on the process of resourcification.

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Consilience: The Journal of Sustainable Development
Iss. 28 (2026)

CONSILIENCE

THE JOURNAL OF SUSTAINABLE DEVELOPMENT

Tunnel vision?: Assessing residents' perspectives of urban flooding and Chicago's 'Deep Tunnel' project

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Abstract

Urban flooding caused by an antiquated mixed sewage-stormwater drainage system affects about 172,000 buildings in Chicago and suburban Cook County, Illinois, incurring billion-dollar costs in property damage, environmental contamination, and personal distress each decade. Though the disproportionate burden of urban flooding in communities of color is well-documented, it is unclear whether large urban flood mitigation projects—such as Chicago's under-construction Tunnel and Reservoir Plan (TARP)—effectively and equitably rectify the situation. Using a mixed-methods approach, this study developed a population-weighted urban flood susceptibility model and utilized that model to recruit residents from high- and low-susceptibility zones and near-reservoir areas. Eighteen semi-structured resident interviews were then thematically analyzed to compare flooding trends and TARP's perceived impacts. Interviewees' experiences illustrate how the uneven burden of urban flooding persists even after TARP's implementation. Better understanding residents' perceptions of their own flood risk under the TARP project helps advance more inclusive and effective stormwater governance, both in Chicago and in other cities building 'deep tunnel' systems.

Author's Note

The interviewer and primary researcher for this project is a long-time Chicago resident, a recent Columbia alum studying sustainable urban development, and a first-time qualitative researcher. Growing up, his parents frequently dealt with sewage backlogs in their basement and driveway. He also leans heavily on the expertise and guidance of his research mentor, advisor, peers, and other professors. They guided him through the complexities of qualitative research, offering valuable insights on ethics, methodology, and interpreting diverse viewpoints. Together, this team's set of (in)experiences played an impactful role in the development of research questions, recruitment of interviewees, and interpretation of their responses.

Keywords: Urban flooding, Urbanization, Floods, Adaptation, Stormwater management

Introduction

Within the past ten years, inland flooding caused $72.6 billion in property damage and 234 deaths in the United States (NCEI 2025). Additionally, increased storm severity and more impermeable urban surfaces place a greater strain on a city's existing stormwater infrastructure. If urban stormwater investment remains stagnant, residents' vulnerability to urban flooding and sewage backups rise. Partly operational since 1991, Chicago's Tunnel and Reservoir Plan (TARP, also referred to as the 'Chicago Deep Tunnel') is a large-scale public works project to build large intercepting sewers to hold sewage in contained reservoirs. This increases the city's vertical sewer capacity to handle larger storms and reduce sewer overflows and urban flooding. Other cities with combined sewer systems have turned to Chicago's TARP as inspiration for their own sewer expansion projects, yet TARP's actual effects on Chicago urban flooding remain understudied (Water Env Fed 2018). As the most fully built-out and comprehensive 'deep tunnel' project globally, Chicago's TARP serves as an informative case study to investigate the efficacy and equity implications of the dozens of 'deep tunnel' systems planned or under construction globally.

Literature Review

Urban flooding imposes significant financial burdens on U.S. communities, with damages averaging $4.5 billion annually between 1980 and 2024 (NCEI 2025). Flood impacts and losses are a product of sudden hazardous changes to natural systems, but the question of who suffers what losses is also dictated by the human-built environment and its embedded social and economic order (Tierney 2019).

Scholarly definitions of flood vulnerability are difficult to pinpoint partly because of the term's vague use across many academic disciplines. This study defines flood vulnerability as the extent to which people are susceptible to harm from floods (Madajewicz 2020; Cutter 2022). This depends on the physical characteristics of the land that person inhabits, like its elevation and slope. But social, economic, and environmental factors—like one's age, native language, or race—also significantly factor into a person's flood vulnerability. This study opts to evaluate communities' flood vulnerability holistically, developing both a quantitative model of urban flood vulnerability for the Chicago area and a qualitative synthesis of resident interviews.

Certain processes associated with urbanization also increase local vulnerability to flood events. As a place urbanizes, minor changes in local elevation and the growth in impermeable surface areas (such as asphalt roads or tile building roofs) alter natural drainage patterns. Cumulatively, small changes in land cover and slope can significantly degrade entire hydrological landscapes; this phenomenon is called 'urban stream syndrome' (Walsh et al 2005; Konrad and Booth 2002).

Urban stormwater infrastructure aims to mitigate these effects. The earliest urban sewer systems, first built in Chicago and Brooklyn in the late 1850s, were designed to drain away the water that accumulated on paved surfaces, but also carried human waste in the same pipes to be treated at a water treatment plant (Burian et al 2000). While these early systems improved urban sanitation and public health, they

occasionally posed significant risks to city residents. When storms overwhelm local sewer capacity, an untreated sewage-stormwater mixture backs up into streets and buildings, or is discharged into rivers to limit human property damage. Today, nearly 860 communities in the United States have legacy combined sewer systems, resulting in an annual discharge of 850 billion gallons of raw sewage into local waterways (EPA 2017).

Deep tunnels, which increase the vertical capacity of combined sewer systems, are designed to mitigate urban flooding by storing stormwater and sewage until treatment plants can process them. This strategy has been adopted in several cities, including Atlanta, Milwaukee, and Washington, D.C., as well as internationally in London and Osaka (Pluth et al. 2021). These systems reduce the amount of untreated sewage discharged into local waterways and provide a temporary solution for managing overflow during storms.

Case Study: Chicago's Tunnel and Reservoir Plan (TARP)

TARP provides a valuable case study for evaluating the impacts of deep tunnel systems. Fueled by growing suburbanization, paved surface acreage doubled in the Chicago region between 1945 and 1965 (Platt 2020). Water landing on this pavement was channeled into an increasingly inadequate combined sewer system.

In the late 1970s, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) proposed a regional solution to reduce river pollution and increase sewer capacity. Tunnels to intercept raw sewage would be burrowed far below ground level, limiting environmental impacts to most of the region, including all of the north and west suburbs. The only above-ground environmental impacts of the new system would be three open-air sewage reservoirs. Two reservoirs, McCook and Thornton Reservoirs, would be constructed in decommissioned limestone quarries adjacent to two low-income communities, while a third smaller reservoir would be built on O'Hare Airport property.

Now mostly operational, the system of tunnels and reservoirs have had a markedly positive impact on regional river quality and biodiversity. The phased implementation of TARP coincided with decreases in fecal coliform, suspended solids, and ammonium nitrogen observed in the Chicago, Calumet, and Des Plaines rivers between 1975 and 2012 (Pluth et al 2021). Likewise, TARP's construction correlates with greater aquatic biodiversity. In 1985, a half-hour fishing trip in the Chicago River caught fewer than 3 native fish species on average; by 2018, that number increased to 13–16 native fish species (Happel and Gallagher 2020).

Still, quantitative approaches to evaluating TARP are limited by the lack of data that is both comprehensive in time and specific in geography. To properly assess TARP's effectiveness, flood data should cover a substantial period and offer enough detail to capture neighborhood-level variations. Unfortunately, no such datasets exist. While the MWRD and third-party organizations collect some relevant data, such as annual totals of combined sewer overflows into local rivers, these figures are reported as region-wide sums and lack the necessary geographic detail. On the other hand,

proxies like 311 calls and insurance claims provide geographic specificity but do not extend far enough back to capture flooding conditions before TARP's implementation. As shown in Figure 1, this gap in data makes it difficult to determine whether the deep tunnels have effectively reduced flood risk in the most vulnerable communities.

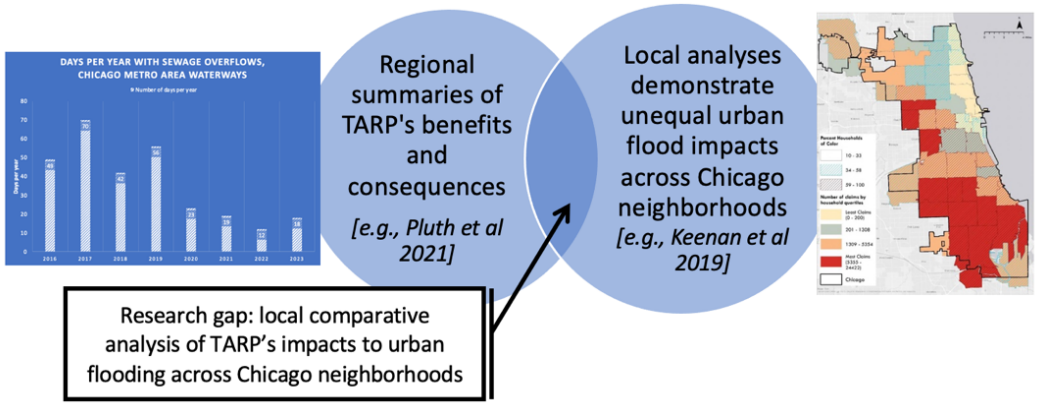

Figure 1. Two research approaches to flooding in Chicago. On one hand, studies such as Pluth et al. (2021) sum up TARP's effects at a regional scale without neighborhood-level detail. On the other hand, studies such as Keenan et al. (2019) highlight neighborhood-level flood risk variation, but without a thematic focus on TARP. Darker regions in the accompanying map from Keenan et al. represent neighborhoods with higher-than-average flood insurance claims per household.

On the precipice of the Chicago Deep Tunnel's construction, Northwestern urban planning professor Stanley Hallett observed that while TARP's environmental impact assessments adequately outlined the "regional benefits and cost of TARP," analyzing the project "merely on the basis of its contribution to regional water quality represents a gross failing of public policy" (Marino 1978). Hallett's words remain relevant today. The tunnels have been built and stormwater has been diverted, but a nuanced understanding of TARP's benefits and impacts on individual communities has yet to be fully developed.

Methods

This study employs a mixed-methods approach, reliant on residents' knowledge of past urban flooding to fill in the gaps in existing data collection. First, a population-weighted version of the Chicago Metropolitan Agency for Planning's Urban Flooding Susceptibility Index (CMAP UFSI) identifies zip codes with the highest and lowest modeled flood exposure. This step helps identify where interviewing residents would most effectively highlight the range of flood vulnerabilities faced by Chicagoans. Secondly, eighteen semi-structured interviews were conducted with residents based on UFSI data and proximity to McCook Reservoir. Finally, transcripts were thematically analyzed to find similarities and differences in the views expressed by low-UFSI, high-UFSI, and near-reservoir residents.

In order to learn how TARP differently affects communities with varying degrees of flood risk, it is important to understand the existing geography of flood risk in the Chicago region. To predict where urban floods occur across the Chicago region, the Chicago Metropolitan Agency for Planning created an open-access roster dataset based entirely on physical land characteristics. These land-based inputs include: relative elevation and topography, water flow accumulation, the historical development of sewer infrastructure, imperviousness of land cover, and relative precipitation trends. Unlike other proxies of urban flood vulnerability such as flood insurance claims, the UFSI uses available data about physical land characteristics. This reduces the chance that flooding in well-resourced communities, which are more likely to have flood insurance, are over-represented. UFSI data was initially collected in 2017 and last updated in 2020.

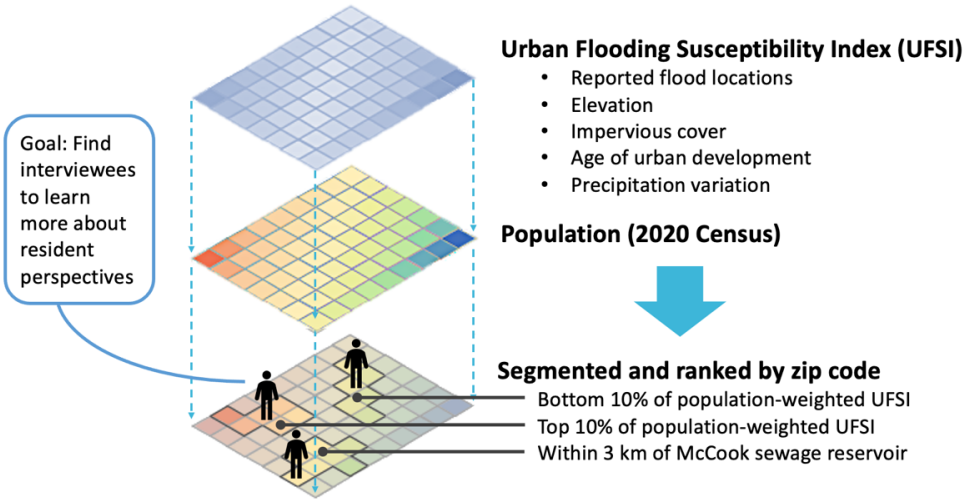

Figure 2. Illustration of methodology using population-weighted UFSI to select interviewees.

To transform the UFSI model into something that more closely resembles *human* flood vulnerability, as opposed to the exposure of a unit of *land*, rasterized population data was incorporated into a modified UFSI. In the case where two pieces of land have the same expected chance to chronically flood, the more densely populated piece of land exposes more people to that flood, which results in an overall greater flood vulnerability. Thus, the following formula was used to calculate the average population-weighted UFSI for a given zip code:

$$Average = \frac{\sum_{cells\ at\ least\ 50\%\ within\ \ zip\ code\ boundary} (population_{cell} \times UFSI_{cell})}{\sum\ population_{cell}}$$

Semi-structured resident interviews

Using information gained from the population-weighted UFSI, Chicago area residents were recruited who met one of three geographical criteria:

a) A zip code within 3 kilometers of the McCook Reservoir

b) Low-flood-susceptibility zones, defined to be the bottom 10% of Cook County zip codes ranked by a population-weighted average of the CMAP UFSI

c) High-flood-susceptibility zones, defined to be the top 10% of Cook County zip codes ranked by a population-weighted average of the CMAP UFSI

Ultimately, of the twenty-three residents recruited, eighteen proceeded to the interview stage. Five residents were excluded for not meeting the geographical criteria for eligibility.

In order to explore residents' personal experiences with urban flooding and TARP's implementation, 40-minute-long semi-structured interviews were conducted with residents individually over Zoom. Each interview was audio-recorded. Participants' answers were transcribed for later thematic analysis after the interview using a transcription computer program. Interview transcripts were verified by relistening and cross-referencing with the recording.

To draw systematized comparisons between the views of Low-UFSI, High-UFSI, and near-reservoir interviewees, Braun and Clarke (2006)'s approach to thematic analysis was used to distill and compare common patterns and meanings within the qualitative data. This approach involves a six-phase process: data familiarization, initial coding, theme generation, theme review, theme definition and naming, and the production of a final report. Initially, transcripts were thoroughly read thrice to ensure immersion in the data, with initial codes generated inductively. Following this, the codes were examined for patterns across the different groups—Low-UFSI, High-UFSI, and near-reservoir—allowing for the identification of both shared and divergent themes. Themes were iteratively refined through discussion and comparison, ensuring they accurately reflected the data while maintaining coherence within each group. Finally, a thematic map was created to visualize the relationships between themes, facilitating the comparison of views across interviewee groups. This process ensured that the analysis was both systematic and transparent, with particular attention paid to the context-specific nature of the themes that emerged.

Results

Urban flood exposure model

When adjusted for population, the UFSI model amplifies the difference between densely-populated, flood-exposed areas from areas that are either not as exposed to floods or not as densely populated. Within Chicago city limits, UFSI values

are more variable within zip codes, reflecting the block-to-block variability in population. While pockets of flood-exposed neighborhoods remain on Chicago's west and southwest sides, the population-weighted UFSI estimates that the densely-populated north lakefront is the most exposed to urban flooding.

Averaging this population-weighted UFSI model by zip code confirms the trends described above. Ranked by their average UFSI, the bottom 10% of zip codes ("Low-UFSI") lie along the periphery of Cook County in more recently-developed suburbs. The top 10% of zip codes ("High-UFSI"), on the other hand, are either immediately north of the city center or on the west/south sides of the city.

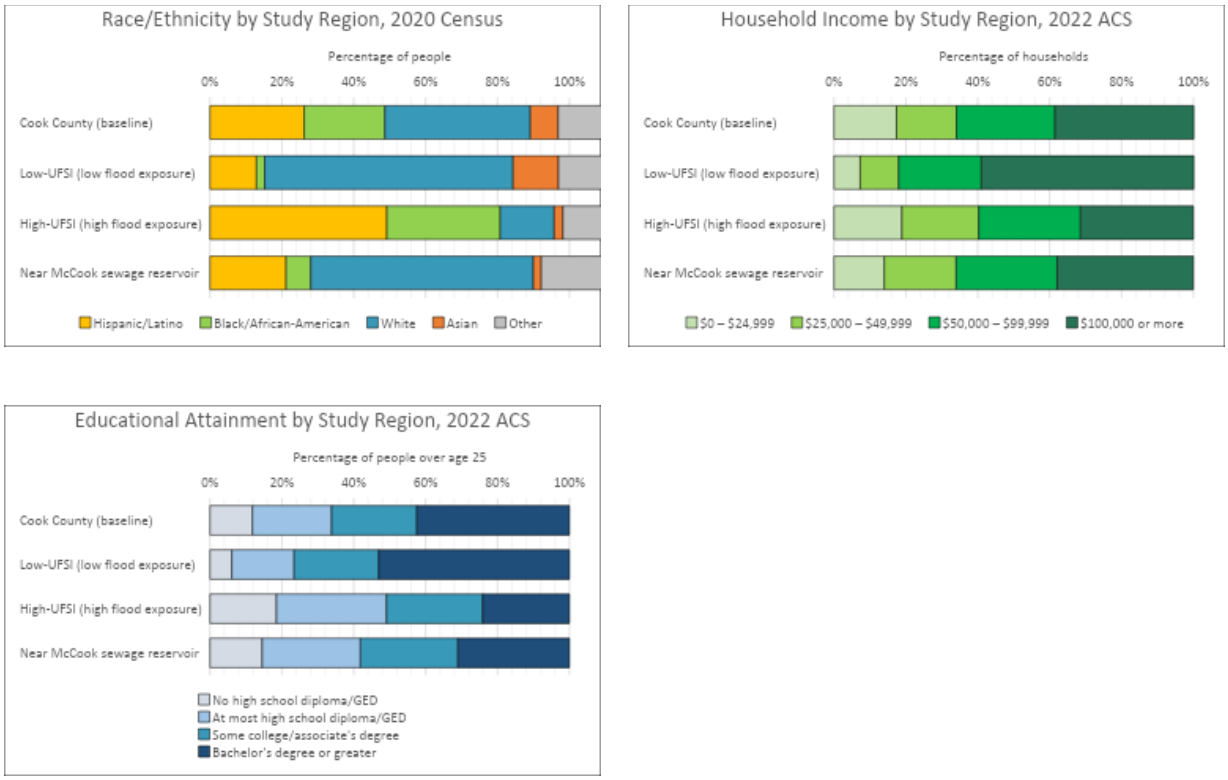

Figure 3. Demographic comparison of three study regions, by race/ethnicity, household income, and educational attainment. Data obtained from 2020 Census and 2022 American Community Survey. Income brackets are in inflation-adjusted 2022 US dollars.

Perceived flood frequency and impacts

Residents near McCook and in High-UFSI areas recalled flooding more frequently than residents in Low-UFSI zones. Residents were also asked to give a subjective stance on whether flooding in their home and community has improved or worsened with time. 66% of High-UFSI interviewees believed that floods had become more frequent over time in their community, while only 16% of Low-UFSI interviewees believed the same.

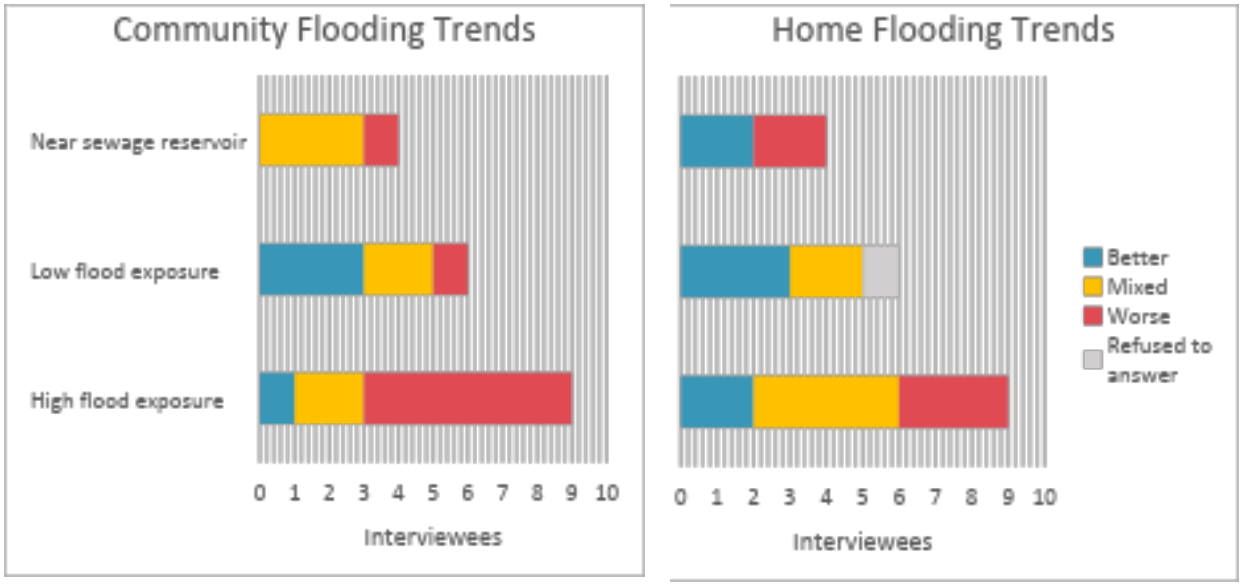

Figure 4. Interviewees' responses to the questions: "How has flooding in your neighborhood/on your property changed over the past 20 years?"

Interviews revealed diverse experiences and concerns regarding personal safety and health risks associated with sewage backflows during flooding events. While no interviewees residing near McCook reported experiencing sewage backflows, 67% of High-UFSI interviewees and 50% of Low-UFSI interviewees recounted instances of sewage intrusion into their basements or driveways. One notable anecdote emerged during an interview with a High-UFSI resident. Following a recent flooding event, the interviewee discovered her basement infested with maggots, which she attributed to sewage intrusion. This incident underscores the potential health hazards and sanitation issues associated with sewage backflows.

Flooding also caused widespread property damage, affecting residents across all study areas. Many spoke of water damage to basements, electrical systems, and personal belongings, with thorough cleanup efforts becoming routine. Public service disruptions were another major concern, particularly among High-UFSI and near-reservoir residents. Flooded streets often halted transportation, making it difficult for residents to access essential services like grocery stores or schools.

TARP awareness and reception

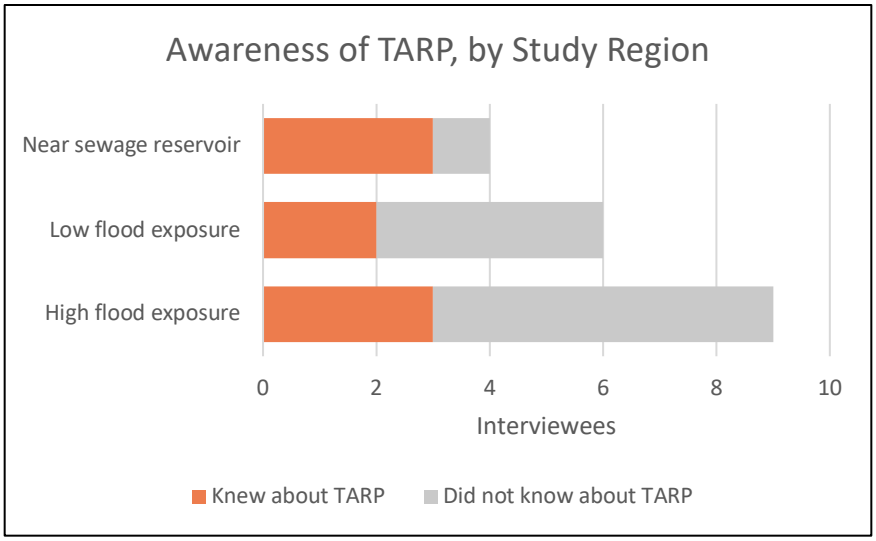

Figure 5. Interviewees' responses to the question: "Have you heard of the Tunnel and Reservoir Plan, or 'Deep Tunnel' project, here in Chicago?"

In both Low-UFSI and High-UFSI zones, residents demonstrated limited knowledge about TARP. One interviewee highlighted the inadequacy of the term "Deep Tunnel" in conveying the project's purpose. Additionally, all but one resident were unfamiliar with the MWRD, the agency responsible for implementing TARP.

Conversely, a majority of residents in the vicinity of McCook sewage reservoir demonstrated awareness of TARP, albeit with differing perspectives on the project's accountability and community engagement practices. Perceptions about TARP were mixed. Two residents suggested that, as a decades-long project, the agency was now mostly unaccountable to their communities. One resident approved of the MWRD's community outreach initiatives to address some of the environmental impacts pertaining to the reservoir.

All 4 interviewees who lived near McCook Reservoir agreed that the number of days with noxious odors had increased over the past ten years. One resident commented that the smells "just become part of the landscape around here, I guess." Compared to the impacts of flooding whose impacts escalated suddenly, sewage odors were more consistent and had a smaller direct impact.

Residents' expectations for regional flood governance

Residents' views on flooding and TARP were part of a broader indirect discussion on what they expect, if anything, from flood adaptation projects and coordinating government agencies. Their responses coalesced around four main expectations: projects should create no new risks, reduce flooding, facilitate strong agency-stakeholder communication, and address social inequities.

The most common expectation among residents from all three study regions was that flood adaptation projects should visibly reduce flooding. Notably, nearly all residents who expressed this expectation framed it within their broader frustration with existing systems. Some wanted fewer floods overall, while others sought reductions in specific impacts like transportation disruptions or property damage. Curiously, one-third of interviewees used figurative language at some point to describe the need for flood projects to visibly reduce flooding. For example, one Low-UFSI resident, a former civil engineer, compared their ideal flood mitigation to a "fortress," reflecting a desire for large-scale, robust protection. Many residents placed a high value on seeing clear, tangible improvements.

Near-reservoir residents were especially concerned about new environmental risks associated with flood mitigation projects. One resident voiced concern, saying, "Let's make sure we aren't creating new sewage problems to replace the old ones." On the other hand, for many Low-UFSI and High-UFSI residents, it was difficult to imagine the extant possibility of other environmental risks until the interviewer more clearly explained the role of the McCook sewage reservoirs in the TARP project.

Beyond residents' expectations for project *outcomes*—including reducing flood risk and limiting other environmental risks—there was also a fairly substantial conversation on what they expected of the planning *process* for these projects. To that end, residents from all three study regions called for more transparent communication between government agencies and residents. The most common context in which residents would voice this expectation of the process was in pointing out existing (non-)communication between the MWRD and residents. One High-UFSI resident remarked, "I'm glad you're talking to us [residents] because our views shouldn't be treated as expendable." Many residents signaled that feeling 'heard' in the planning process was a necessary goal for agencies to consider in their regional flood adaptation projects. Still, not all residents who talked about increasing community engagement did so in an aspirational manner. One recalled her experience with a land-use project unrelated to stormwater management, attributing the "disorienting" community engagement process to an imbalance in expertise between agency members and residents.

The final main expectation residents expressed was that flood adaptation projects should account for existing social inequities. All interviewees agreed that flood exposure and risk varied across the city and tended to disproportionately affect marginalized communities. Low-UFSI residents generally trusted that TARP was designed to benefit flood-prone areas, particularly communities of color. One resident expressed optimism, saying, "My intuition is that these kinds of projects are targeting the flooded parts from the get-go. You kind of have to trust the government to be held responsible." In contrast, High-UFSI residents were more skeptical, with many believing that wealthier or politically connected neighborhoods would benefit more from TARP than their own.

Occasionally, interviewees expressed concern for the large capital cost of the TARP project. Some interviewees were concerned about the high costs of projects like TARP, prioritizing fiscal responsibility, while others, especially in flood-prone areas,

valued the potential for flood risk reduction more than the project's capital costs, favoring expensive, robust flood protection.

Discussion

Residents offered a comprehensive picture of Chicago's urban flooding and its regional flood governance. Their voices moved beyond a binary evaluation of TARP as either a success or a failure. Rather, their perspectives included well-defined ideas about the role that equity, expertise, community engagement, and other environmental impacts should have in evaluating TARP's neighborhood-level effects. Using their perspectives, four cross-cutting themes were created to partly explain how residents with different flood susceptibilities evaluate TARP.

Historical Continuity of Local Flooding Challenges

Residents' anecdotal experiences with urban flooding align with Chicago's broader history of water management problems. From the installation of combined sewer systems to the reversal of the Chicago River, local leaders have long regarded water both as a commodity and a nuisance (Platt 2020). TARP is the latest in a tradition of large-scale infrastructure projects aimed at addressing the region's water-related problems, like sanitation and urban flooding.

This uneasy relationship between the city and its water is a recent development. Native American Chicagoans, for example, share parables which emphasize a deep interconnection between local water and land-based urban ecological systems: "Muskrat is an earth diver. He finds home in shadowy wetlands—relational dynamisms between land and water—amongst the plant medicines that grow here" (Bang et al 2014).

Their view contrasts with the notion expressed by all interviewees: that water in urban areas must be controlled. One Low-UFSI resident argued that the MWRD ought to "build a fortress against floods." While this statement reflects a common perception that large infrastructure projects offer absolute security, it is also the product of a cultural divergence in understanding water's role in urban spaces. Still, the persistence of flooding has reinforced the demand for such projects. About 70% of interviewees agreed that urban flooding had worsened for them over the past 20 years.

Idealized, Competing Visions for Regional Flood Governance

Residents shared multiple criteria by which they evaluate a flood mitigation project. Most often, residents stressed the need for projects to visibly reduce flooding. This urgency was reflected in all 18 interviews, where the idea of flood impact reduction was mentioned 89 times.

The emphasis on other goals varied across study regions. Near-reservoir residents, for example, prioritized avoiding new risks, such as those posed by sewage reservoirs. High-UFSI residents, likeliest of the three populations to be Black or

Brown, emphasized social equity. This variation highlights how residents' experiences with environmental injustice shape their flood governance priorities. Interestingly, some residents projected their own imagined realities onto other regions. Those in Low-UFSI regions assumed TARP primarily benefited High-UFSI areas, despite the skepticism from High-UFSI residents. Such disparities illustrate the complex, sometimes contradictory expectations that residents hold for flood governance.

Outcome Gaps: Spatial Inequities in Environmental Risk

Flood risks varied significantly across the three study regions, with High-UFSI residents reporting more frequent and severe flooding compared to Low-UFSI areas. High-UFSI residents also recounted sewage backups during storms, which Low-UFSI and near-reservoir residents did not experience. These differences underscore a broader pattern of environmental inequity, where Chicago's Black and Latino neighborhoods bear disproportionate flood-related burdens (Keenan et al 2019; Sinha 2023).

McCook Reservoir also represented a major concern for near-reservoir residents, who described it as a "locally unwanted land use." Complaints about foul odors, groundwater contamination, and local economic impacts reflect the historical environmental injustices these communities have faced, such as the repurposing of former limestone quarries into sewage reservoirs. These patterns mirror broader trends of siting environmentally hazardous infrastructure in low-resistance communities, exacerbating existing inequalities (Bullard 1993).

Process Gaps: Lapses in Public Engagement

Across all regions, most residents expressed dissatisfaction with the MWRD's public engagement efforts, regardless of their neighborhood's flood susceptibility. Public awareness of TARP was low, particularly in Low-UFSI and High-UFSI areas, where only 33% of interviewees had heard of the project before their interview. Residents near McCook were more familiar with TARP, though they were largely unaware of mitigation efforts intended to reduce odors from the reservoir.

The desire for better agency communication was expressed across all regions. Some residents were frustrated with the lack of transparent dialogue about TARP's goals and trade-offs. While some residents expressed hope that improved communication might lead to more co-creative flood resilience planning, others feared that increased public involvement could undermine the expertise of engineers and planners.

Research Limitations

Several limitations exist across the modeling, screening, and interviewing phases of this study. The primary confounding factor for the results is the presence of other smaller, local stormwater management projects that were implemented concurrently with TARP. In some neighborhoods, green infrastructure and low-impact development strategies also helped to manage flooding locally, meaning that

observed variations in flood-related outcomes could have resulted from a combination of these efforts rather than TARP alone.

The population-weighted index developed during the modeling stage of the study is an incomplete measure of vulnerability to urban flooding. The UFSI relies on a set of physical and human factors that are typically associated with flood exposure. But other social and infrastructural factors, like race/ethnicity, socioeconomic status, homeownership, access to transportation, and English proficiency, were not included and ought to be considered in a full assessment of flood vulnerability (Madajewicz 2020).

Interviewees were solicited via community organizations through convenience sampling; the opinions of the selected interviewees do not constitute a representative sample of Chicago-area residents. Interview responses should not be regarded as totally objective interpretations of flooding events and government actions, but given the lack of quantitative data locally on urban flooding, they represent a valuable source of information about the county's urban flood governance. Future research could benefit from a longitudinal approach that tracks residents' perceptions of flooding over time, which might give deeper insights into the long-term impacts of TARP.

Conclusion

Chicago's TARP is the world's first example of a large-scale 'deep tunnel' project meant to address local waterway pollution, urban flooding, and the compounding effects of climate change in urban areas. Many cities are now designing or building similar deep-bored systems that aim to increase a sewer system's vertical capacity (Water Env Fed 2018). But research on the effects of these 'deep tunnels' remains limited, necessitating this case study on TARP to guide the future stormwater governance of Chicago and other cities.

Through eighteen semi-structured interviews, residents across Low-UFSI, High-UFSI, and near-reservoir areas assessed their neighborhood's flooding trends as they coincided with TARP's implementation. Their nuanced views of large-scale flood adaptation projects like TARP often extended on their personal experiences with flooding. Residents also evaluated TARP with a few implicit criteria that could be considered 'benchmarks' for a successful urban flood mitigation project: projects should reduce flooding, projects should create no new risks, agencies should communicate with residents, and agencies should account for inequity. Knowledge about other technical and political aspects of the TARP proposal was low among residents, and did not seem to heavily factor into residents' evaluations.

The earliest proponents of 'deep tunnels' claimed these systems would "eliminate" environmental risks like urban flooding and pollution (MWRD 1966). However, residents' varied flooding experiences suggest that deep tunnels are modifiers—not eliminators—of existing "social topographies of risk" (Taylor 2015). Under TARP, urban flood risk still disproportionately affects Cook County's High-UFSI neighborhoods, which are poorer, less educated, and more Black/Latino/Hispanic than the county average. While it is difficult to directly link

TARP to these inequitable outcomes directly, the evidence indicates a need for more equitable and effective flood management strategies going forward to address current disparities.

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Consilience: The Journal of Sustainable Development
Iss. 28 (2026)

CONSILIENCE
THE JOURNAL OF SUSTAINABLE DEVELOPMENT

Rain Gardens and Monsoon Flood Management in Mumbai: A Comparative Assessment of Dense Inland Catchments and Newly Reclaimed Coastal Landscapes

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Abstract

Mumbai experiences 2,200–2,800 mm of annual rainfall, much of it concentrated in a few monsoon weeks, producing chronic flooding in low-lying neighbourhoods such as Hindmata Junction. At the same time, the Mumbai Coastal Road project is creating roughly 130 acres of new reclaimed parkland along the city's western shore. This paper asks how much practical potential rain-garden systems have to reduce localised waterlogging in Mumbai's monsoon climate, and how that potential differs between dense inland bowls and newly reclaimed coastal open spaces. The study adopts an identification-and-description strategy using secondary data: Indian Meteorological Department rainfall records, Municipal Corporation of Greater Mumbai drainage reports, media coverage of recent flood events, and international literature on rain-garden performance in tropical cities. Simple volume estimates and typology-based reasoning are used to compare feasible rain-garden configurations at Hindmata and along the Coastal Road parks. Results show that at Hindmata, extreme inflows from a ~2 km² catchment (on the order of 150,000–170,000 m³ per hour during cloudbursts) dwarf the storage that micro-scale rain-garden typologies could realistically provide, limiting their role to mitigating kerb-side ponding and improving water quality. Along the Coastal Road, by contrast, the combination of smaller contributing catchments and contiguous programmable parkland allows park-integrated bioretention basins and bioswale corridors to intercept a meaningful fraction of runoff. The paper argues that urban form is a decisive filter for the feasible role of rain gardens in dense coastal megacities, with implications for how Mumbai and similar cities deploy green infrastructure for monsoon resilience.

Author's Note

This article developed from my final paper for the MSc Sustainability Management course "Critical Urban Infrastructure for Sustainable Development" at Columbia University. During the course I became interested in why some Mumbai neighbourhoods, such as Hindmata Junction, remain chronically waterlogged despite

repeated drainage upgrades, and whether green infrastructure could realistically help. I focus on rain gardens because they are often promoted as simple, low-impact climate-adaptation measures, yet their feasibility in extremely dense, monsoon-affected cities is rarely interrogated. By comparing Hindmata's inland bowl with the new Coastal Road reclamation parks, the article aims to show in accessible terms where rain gardens can and cannot contribute to stormwater management, and why urban form matters for sustainable development. I hope the work can support more place-sensitive approaches to blue–green infrastructure in Mumbai and other coastal megacities.

Keywords: Rain gardens, Green infrastructure, Stormwater management, Mumbai, Monsoon flooding, Critical infrastructure

Introduction

The city of Mumbai receives 2,200–2,800 mm of rain each year, over half of it falling within four to six weeks of the peak monsoon (Zope et al., 2016). Most of the stormwater system, built more than a century ago, was designed for only 25–50 mm/hour of rainfall (Gupta, 2009; Zope et al., 2016). Recent monsoons now bring short bursts of 70–80 mm/hour that routinely exceed this capacity. The network also discharges through more than 200 outfalls to the Arabian Sea and tidal creeks, so during high tide tide-lock prevents gravity drainage and water backs up into low-lying areas. These limits are most visible in chronic flooding that shuts down rail lines and roads, interrupts informal work, and keeps large sections of the city's lowlands under water for hours.

Among the best known examples is Hindmata Junction, repeatedly listed in municipal records as a hotspot of chronic flooding in Mumbai (MCGM, 2023). Hindmata sits in a natural depression where three micro-catchments converge; intense rainfall rapidly collects in this bowl-shaped landform and produces flash flooding (Tripathy et al., 2024). The area also receives runoff from highly paved upstream neighbourhoods, so very little water infiltrates before it reaches the junction. Despite dedicated micro-pumping stations, regular desilting, and drain-widening works, the junction still floods several times every monsoon. This illustrates the structural limits of grey infrastructure in catchments whose topography and tidal regime restrict the physical movement of water and leave engineers with only incremental retrofit options.

These physical realities have shaped a common perception that green infrastructure (GI) such as rain gardens, bioswales and bioretention systems is impossible in Mumbai. The argument points to the city's heavy rainfall, narrow rights-of-way and extremely limited open space. Mumbai's per-capita open space is among the lowest of global megacities. Dense urban form leaves little surface available for infiltration features, reinforcing the idea that GI can only play a symbolic or cosmetic role and that serious flood management must rely on pumps, sea walls and widened concrete drains.

However, this assumption is being challenged by evidence from other tropical and monsoon-intensity cities. Studies from Singapore, which receives rainfall comparable to Mumbai, show that engineered bioretention systems such as curbside planters and modular tree trenches can significantly reduce peak runoff even during heavy tropical storms (Lim et al., 2021; Neo et al., 2022). Because they are embedded in existing streetscapes, these systems also improve shade and microclimate without requiring large parks. In southern China, field experiments demonstrate that rain-garden systems maintain infiltration performance under 45–55 mm/hour storms, within the range of typical Mumbai monsoon bursts (Chen et al., 2023). Syntheses of global studies consistently report runoff reductions between 30 and 90 percent, depending on soil media, vegetation, and construction details (Nazarpour et al., 2023; Vijayaraghavan and Basco, 2021). Together, these results indicate that high-intensity rainfall alone does not preclude successful GI implementation and that the key design question is where and at what scale such systems can be sited.

In this respect, urban morphology is the more decisive constraint in Mumbai. High-density inland catchments offer very little space for infiltration systems larger than small planters or bioswales tucked into leftover corners. Such micro-scale installations can mitigate local ponding at junctions and footpaths but cannot materially change basin-scale flooding governed by pump capacity, high-tide timing and the limited diameter of trunk sewers. By contrast, the recently reclaimed landscapes along the Mumbai Coastal Road create a rare opportunity to test GI at scale. The project will add roughly 130 acres of continuous, city-owned open space in the form of parks, promenades, and landscaped areas (Times of India, 2025; Indian Express, 2024). Unlike older inland neighbourhoods, this reclaimed coastal land is not constrained by existing buildings or buried utilities, making it possible to integrate larger, interconnected bioretention systems, detention lawns and tree trenches into the public realm as part of the project's promised open-space network.

Against this background, the present research examines the question: *"How much practical potential do rain-garden systems have to reduce localised waterlogging in Mumbai's monsoon climate, and how does their feasibility differ between dense inland catchments such as Hindmata Junction and newly reclaimed open spaces along the Coastal Road?"*

The main argument of this paper is that rain gardens can have a small, complementary role in thickly constructed inland basins, but they have an important, scalable potential in the open reclaimed landscapes of the Coastal Road. This particularity is critical in informing pragmatic, place-based solutions to stormwater resiliency in Mumbai.

Literature Review

Rain Gardens and Bioretention Systems

Bioretention systems or rain gardens are vegetated shallow depressions that are designed to receive, infiltrate, and temporarily retain stormwater runoff through the use of porous media and adapted vegetation (Vijayaraghavan and Basco, 2021). They are normally composed of surface ponding layer, engineered soil mix, transition layer of sand and sometimes an underdrain that enables a controlled discharge to neighboring drains. These elements collaborate to reduce the velocity of the run-off, enhance their infiltration, better the quality of water, and even out the peak flows (Nazarpour et al., 2023).

There is evidence of high hydrologic performance in areas of the monsoon. Rain-garden installations in southern China showed resistance to storm bursts of 45 to 55 mm/hour and had excellent infiltration, which was also resilient as per the situation in Mumbai (Chen et al., 2023). Integrating rain-garden systems into high-density residential and commercial areas, Singapore has achieved the success in reducing the peak flow volumes and increasing the water quality indicators including suspended solids and nutrient levels (Lim et al., 2021; Neo et al., 2022). The versatility of bioretention in dissimilar climates is also noted in a global systematic review which indicates runoff-reduction efficiency between 30 and 90% depending on the filter

media, vegetation type, ponding depth, and landscape structure (Nazarpour et al., 2023).

The maintenance aspect is a major concern that affects the long-term performance. When the upper layer of soil is clogged, the efficiency of infiltration may decrease, and to eliminate the sediment and replace the plants, this process may need to be carried out periodically (Vijayaraghavan and Basco, 2021). In cities characterized by elevated road-dust levels and intense construction/construction activities, e.g., in Mumbai, there has to be an adaptive consideration in maintenance issues.

Rain-Garden Typologies and Urban-Form Constraints

Rain gardens vary greatly depending on the size of land. Smaller typologies that are mostly commonly used in dense urban environments include curbside bioswales, modular tree trenches, and planter-box rain gardens. They Capture runoff from adjacent lanes / sidewalks and are typically designed for the *first* few centimetres of rainfall and to protect inlets. These systems can be installed in the small rights-of-way and can capture runoff of pavements and small roads (Lim et al., 2021; Neo et al., 2022). They mostly address local ponding and water quality, not whole-basin flooding and have a tendency to be localised with their hydrologic benefits though capable of increasing infiltration and decreasing surface ponding at certain locations.

The larger typologies, such as park-integrated bioretention basins, wet-meadow filtration zones, and bioswale corridors, demand continuous open-space space and deeper soil profiles (Przestrzelska et al., 2024). These systems have greater storage capacity, often sized for 10–50 mm storms over larger areas, a higher infiltration rate, and a connectivity between a variety of cells that generate a much greater cumulative hydrologic impact. Hence, they can contribute meaningfully to peak-flow reduction when networked. These typological differences directly relate to Mumbai. The spatial limitations of GI to micro scale facilities in inland catchments like Hindmata reduce their role in reducing the total floods. On the other hand, the Coastal Road reclamation provides adequate land and continuity to build precinct-based GI networks that will be capable of handling runoff in better ways. The rest of this paper therefore evaluates which of these typologies is realistically deployable at Hindmata and along the Coastal Road, and what hydrologic role each can play in those contrasting urban forms.

Blue–Green Infrastructure and Stormwater Resilience

Blue-green infrastructure (BGI) is a combination of natural and engineered systems that minimize the risk of floods and offer ecological and social amenities. The BGI literature emphasizes the need to have a mix of grey infrastructure (pumps and culverts) and distributed green systems to slow, store, and filter runoff (Perrelet et al., 2024). Such hybrid systems have been demonstrated to minimize peak runoff, augment the quality of water and make the climate more resilient through a diversified drainage pathway (Przestrzelska et al., 2024).

In regions with monsoon strength, effective BGI requires proper soil depth, hydraulic connectivity of the green spaces and care regimes. Research indicates that BGI is best used in open and continuous landscapes as opposed to separate installations (Chen et al., 2024). This observation is in direct design with the opposing urbanistic patterns of Mumbai: inland urban areas do not possess the more or less continuous form necessary to enable effective BGI, whereas the newly reclaimed coastal areas provide the spatial preconditions of networked interventions.

Mumbai's Drainage System and Flooding Characteristics

The BRIMSTOWAD master plan defines the drainage system in Mumbai and establishes a complicated network of drains, culverts, and outfalls (MCGM, 2023). Most structures are still under-sized with regards to current rainfall extremes despite upgrading. The tide-locking is a common issue since when the tide is full, the outlets cannot drain into the coastal waters (Gupta, 2009). As a result, regions that fall below mean sea level or those that are in natural depressions flood very fast even in an occurrence of monsoons.

Flood-mapping projects supported by crowdsourcing verify Hindmata as one of the most at-risk inland basins of Mumbai when it comes to floods, and frequent flooding has been reported throughout the monsoon seasons over the past years (Tripathy et al., 2024). Conversely, the Coastal Road reclamation brings forth an open space, not available in the thick urban fabric in Mumbai before. Planing reports and media suggest that this new land is being developed into parks, promenades, and public spaces in about 130 acres of land (Times of India, 2025; Indian Express, 2024). This level of open space opens new possibilities in the system of rain-gardens in the city stormwater policy.

Research Design

Research Approach

This research is based on an identification-and-description approach that is appropriate in infrastructure research where experiments or hydrological models are not possible. The intention is to collect, analyse and cross-examine the secondary data that sheds light on the way in which rain-garden systems would operate in the monsoon climate of Mumbai. The method focuses more on contextual feasibility and not predictive modelling. The values of benchmark performance are determined based on available evidence of the tropical cities and compared to the flood-prone inland basins in Mumbai and the recently reclaimed coastal landscape in Mumbai.

Data Sources

Climatic information is a fundamental part of the study. The intensity of rainfall in the 2020 to 2024 was taken based on Colaba and Santacruz observatories of the India Meteorological Department. These two stations offer comparative views on the distribution of rainfall in the island city.

The data on institutions were obtained at the Municipal Corporation of Greater Mumbai in the Storm Water Drains Department (MCGM, 2023). These are records of the type of pumping-stations, drainage-zone interconnection, and annual performance statements. The comprehensive literature base presented empirical data on other cities in the tropics or the monsoon. Singapore, southern China, Thailand, and Chennai studies provided hydrological performance data of rain gardens (Nazarpour et al., 2023; Chen et al., 2023; Lim et al., 2021). These performance standards are essential to assessing the constraints of feasibility of Mumbai.

Case Selection Rationale

Hindmata Junction is a situation of the worst possible inland flooding where geomorphology, density and drainage limitation meet. It is fed by a catchment area of approximately 1.9-2.3 km^2, and it is located in a natural depression that is approximately 1.5 m below the surface of the rest of the land (Tripathy et al., 2024). It is particularly dependent on pumps, which makes it a perfect example of considering micro-GI (small green infrastructure).

Mumbai Coastal Road reclamation has been chosen as a contrasting case since it creates a programme-receptive open land of almost 130 acres with no existing built structure (Times of India, 2025). In contrast to Hindmata, the reclaimed land is permitting structured soil profiles, adaptable grade, and decentralized drainage - circumstances applicable in the medium and large scale rain gardens.

Analytical Strategy

The analysis proceeds through structured comparison. Each case is evaluated across:

(a) “hydrological load characteristics”;

(b) “available surface area and soil depth”;

(c) “drainage pathways and tide interactions”;

(d) “compatibility with internationally observed rain-garden performance values.”

Feasibility is evaluated by numerical indicators, which include estimates of catchment inflow, pump capacity, rainfall and infiltration benchmarks. The findings section provides the tables of the analysis of these values. This is a purposefully descriptive and numerically informed design: it is not flood modelling; rather, it is realistic infrastructural judgement based on quantitative evidence.

Findings / Results

Hydrological Comparison of the Two Study Areas

Mumbai's inland and coastal landscapes respond very differently to monsoon rainfall. To clarify these contrasts, Table 1 summarises the key hydrological parameters relevant to rain-garden feasibility.

Table 1. **Hydrological Parameters Relevant to Rain-Garden Feasibility**

Parameter	**Hindmata Junction**	**Coastal Road Reclamation**	**Sources**
Annual rainfall	2,317–2,846 mm	2,317–2,846 mm	IMD; Zope et al., 2016
Peak 1-hr rainfall intensity	78–92 mm/hr	62–74 mm/hr	IMD
Catchment size	1.9–2.3 km²	0.35–0.40 km² (localised)	Tripathy et al., 2024; MCGM
Natural drainage pathway	No (basin)	Yes (towards sea)	MCGM, 2023
Dependence on pumps	Very high	Moderate to low	Indian Express, 2023
Suitable GI scale	Micro-GI only	Medium–large-scale GI	Lim et al., 2021; Neo et al., 2022

Hindmata Junction: Quantitative Constraints on GI Performance

Hindmata's inflow volumes during cloudbursts illustrate why micro-GI cannot meaningfully reduce flooding. A typical intense monsoon hour of 80–90 mm/hr falling on a ~2 km² catchment produces an inflow of:

$$\text{Inflow} \approx \text{rainfall intensity} \times \text{area}$$

$$= 0.085\ \text{m} \times 2{,}000{,}000\ \text{m}^2$$

$$\approx 170{,}000\ \text{m}^3 \text{ of runoff/hour}$$

In comparison, the Hindmata pump capacity is:

$$3{,}000\text{–}3{,}500\ \text{m}^3/\text{hr}\ \text{(Indian Express, 2023)}$$

This means that during a heavy rainfall hour, incoming water exceeds pump removal capacity by a factor of ~50:1.

Internationally, high-performing rain gardens can detain between 40–150 mm of rainfall, depending on design depth and media composition (Nazarpour et al., 2023). Applied to Hindmata's context, even if the city installed multiple curbside rain gardens (for example, 20 rain gardens at 50 m² each), total detention would be:

$$\text{Total storage} \approx 50\ m^3 \text{ to } 150\ m^3$$

against inflows of:

$$170{,}000\ m^3$$

This is less than 0.1% of the runoff entering the basin.

In practice this confines Hindmata to micro-typologies such as curbside bioswales, planter-box rain gardens, and small tree trenches at junctions, whose function is to intercept the first centimetres of runoff and protect inlets rather than provide basin-scale storage. Thus the numbers confirm that rain gardens in Hindmata cannot meaningfully offset incoming floodwater volumes. Their feasible contribution is limited to reducing very localised ponding — for example, capturing the first 10–20 mm of roadway runoff — and filtering debris before it enters the drains.

Coastal Road Reclamation: Numerical Feasibility of Large-Scale Rain Gardens

The Coastal Road reclamation, by contrast, allows rain gardens of significantly larger size and depth. Because reclaimed land can be graded, rain-garden basins of 500–3,000 m^2 are feasible within park designs. If a set of 10 such basins were installed, each with a storage depth of 0.3–0.5 meters, total on-site stormwater detention would be:

$$\text{Storage} \approx 10 \times (1{,}000\text{–}3{,}000\ m^2 \times 0.4\ m)$$

$$\approx 4{,}000\text{–}12{,}000\ m^3$$

This storage potential is several orders of magnitude higher than anything possible inland. It still does not replace the need for grey drainage, but it substantially reduces peak runoff before reaching the coastal outfalls.

International studies show that large-scale bioretention systems in parks can reduce peak flows by 20–60% in tropical cities (Lim et al., 2021; Neo et al., 2022). When applied to the Coastal Road's smaller catchment (~0.35–0.40 km^2), these reductions can meaningfully decrease loads entering outfalls during intense rainfall.

To illustrate, an hour of 70 mm/hr rainfall over 0.35 km^2 produces:

$$\text{Runoff} \approx 0.07\ m \times 350{,}000\ m^2$$

$$\approx 24{,}500\ m^3/hr$$

If rain-garden systems intercept 20–60%**,** this translates to:

$$\approx 5{,}000\text{–}15{,}000\ m^3/hr \text{ reduction}$$

This aligns closely with the feasible detention capacity of the reclaimed park systems, confirming that GI can make a measurable difference in this context. These

numbers are only achievable with larger typologies – park-integrated bioretention basins, bioswale corridors along promenades, and linear tree-trench systems flanking internal access roads – which the 130 acres of reclaimed parks can physically accommodate.

Table 2. *Numerical Comparison of GI Impact Potential*

Metric	**Hindmata**	**Coastal Road**	**Interpretation**
Hourly inflow during storm	~170,000 m^3	~24,500 m^3	Coastal catchment is smaller → GI more effective
Max feasible GI storage	<200 m^3	4,000–12,000 m^3	Coastal Road allows deeper, larger basins
GI potential runoff reduction	<1%	20–60%	Large-scale GI feasible only at coast
Pump dependency	Extreme	Low–moderate	Key factor shaping feasibility

Interpretive Findings

The numerical analysis yields main finding: urban structure rather than rainfall determines GI viability in Mumbai. Rainfall intensity at the sites is similar, but their hydrological characteristics differ significantly. Hindmata is fed by large basin inflows and has no gravity outflow, while the Coastal Road reclamation receives smaller volumes and can drain to the sea. As a result, rain gardens in Hindmata serve micro scale purposes, whereas those on the Coastal Road can reduce peak flows and stormwater loads.

Discussion

The comparative evidence shows that practicality of rain garden systems in Mumbai is largely dependent on the urban form and less on the monsoon rainfall intensity. Hindmata and the Coastal Road share the same climatic conditions: an average precipitation of over 2,300 mm per year, frequent cloudbursts higher than 70 mm per hour and tidal movements that make drainage difficult (Zope et al., 2016; Rajeevan et al., 2008). At Hindmata, a large contributing catchment drains into a bowl shaped depression with narrow rights of way, compact subsurface utilities and seasonally high groundwater. In such a geometry the inflows during peak monsoon events rapidly exceed what even the highest performing international rain gardens designed for 40 to 150 mm storms can offset at basin scale (Nazarpour et al., 2023; Chen et al., 2023). The physical environment leaves almost no room for deep infiltration systems, with both space and depth constrained. Even if several rain gardens were placed along the footpaths, their total storage would remain small compared with the inflow, and rising groundwater reduces infiltration capacity and sustained storage. These limitations mean that GI in Hindmata can only play local roles, such as slowing roadway runoff or trapping debris before it enters the drainage system, rather than tackling the wider problem of depression scale flooding.

In comparison, the Coastal Road reclamation offers a spatial context compatible with principles from global blue green infrastructure literature. BGI systems are most effective where continuous surface areas, sufficient soil depth and adjustable ground slopes can be shaped toward decentralised infiltration areas, all of which the reclaimed parks provide (Perrelet et al., 2024; Przestrzelska et al., 2024). Because the land is newly created, designers can regulate soil composition and install permeable substrates with infiltration rates comparable to high performing systems in Singapore and China (Lim et al., 2021; Neo et al., 2022). Numerical analysis indicates that these systems can provide substantial detention volumes and sizeable reductions in peak runoff while gravity outfalls along the coast allow discharge through much of the tide cycle, unlike Hindmata where pump capacity constrains volumes (Nazarpour et al., 2023). In this setting, rain gardens complement rather than substitute the drainage system by reducing the final load on engineered channels.

These opposing results demonstrate a valuable policy lesson: rain gardens in Mumbai do not have the same effect in all locations. GI cannot substitute grey drainage systems in dense inland regions and should not be promoted as the primary flood reducing measure there. Rather, micro GI can support the reduction of small scale ponding, enhance local water quality and help keep street inlets clear by filtering sediment and debris. These localised benefits are not irrelevant but must be framed realistically; overstating their potential risks spending on interventions that do not change basin scale flood occurrence.

Rain gardens may take a different and more significant role in open coastal settings. The new parks created along the Coastal Road give Mumbai a rare chance to create a continuous blue green space that harnesses stormwater flows, cools them and filters them before discharge to the sea. The location of bioretention systems here can demonstrate how hybrid drainage, combining engineered conveyance with natural infiltration, can be incorporated into future reclamation or redevelopment projects. This kind of demonstration is especially significant in a city where land scarcity has long limited the ability to test urban nature solutions at scale.

Spatial differentiation between the two cases supports the importance of site based urban resilience planning. Instead of applying identical green infrastructure solutions across the city, Mumbai needs a zoning based strategy that identifies areas where they can be scaled up, areas where only micro scale installations are feasible and areas where they add little value. Inland catchments still require sustained investment in pumps, outfall management and real time coordination of tides and rainfall, while suburban and coastal regions offer opportunities for more integrated and dispersed GI networks.

The results also suggest that future flood management in Mumbai should be organised around hybrid systems that combine grey and green components. This concept of hybridisation aligns with global research on BGI, which highlights the value of diversifying the routes through which water moves during storms (Kaur et al., 2022; Chen et al., 2024). Such approaches can be tested on the Coastal Road reclamation through scalable, interconnected bioretention systems. Success along this corridor

could shift social and institutional attitudes toward GI by showing that green systems supplement, rather than replace, engineered infrastructure.

Lastly, the analysis offers a broader perspective for other megacities in coastal areas facing similar constraints. The diversity of landscapes in Mumbai suggests that monsoon strength is not the sole determinant of GI viability. Instead, land availability, catchment size, drainage gradients and the presence of programmable soil are the decisive variables. Focusing on micro geographies rather than general assumptions about climate and density makes it possible to identify where infiltration based systems are structurally compatible and to target resilience planning more effectively.

Conclusion

The study explored the feasibility of rain garden systems in two radically different monsoon settings in Mumbai: the inland basin of Hindmata Junction and the newly reclaimed parks of the Coastal Road. It found that the feasibility of green infrastructure is organised by urban structure rather than rainfall, using climatic data, municipal infrastructure records, international rain garden literature and numerical comparison. The large hydro catchment, bowl shaped topography, small surface corridors, shallow utilities and reliance on pumps combine to make rain gardens in Hindmata largely ineffective for reducing flooding. They provide only micro scale benefits like reducing ponding on crowded roadways and filtering debris before it reaches the drainage network. These modest functions are valuable but negligible at basin scale, where inflows of more than 150,000 m3/h dominate the most severe storms.

The Coastal Road reclamation introduces almost 130 acres of programmable open space, offering conditions for medium and large scale bioretention systems. The reclaimed land can carry rain garden systems to cut peak runoff while also allowing designers to build ground gradients, soil profile engineering and multiple bioretention basins into park landscapes. Such systems support the coastal drainage network and provide a chance to test ambitious hybridizing blue green infrastructure in Mumbai.

The study concludes that rain gardens in Mumbai are possible but highly sensitive to space and urban geometry. Pump centred solutions supported by micro GI are needed inland, while coastal reclamations and new developments offer opportunities for green infrastructure networks. By recognising and planning for this difference, Mumbai can better allocate resources and build a more region specific monsoon resilience strategy.

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Consilience: The Journal of Sustainable Development
Iss. 28 (2026)

CONSILIENCE
THE JOURNAL OF SUSTAINABLE DEVELOPMENT

The Efficacy of Solid Waste Management Methods in Mto Wa Mbu, Tanzania

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Abstract

Solid Waste significantly contributes to the degradation of both public and environmental health, making effective waste management a critical issue for countries worldwide. By 2050, global waste production is projected to increase by up to 70%, with sub-Saharan Africa expected to more than triple its current waste levels [7]. Although Tanzania has made notable developmental strides, evident in rising GDP and declining poverty rates [17], the country continues to face challenges in waste management due to limited financial resources for public policy in this sector. This study uses a standardized observational checklist, along with an interview, and literature reviews, to gather data and assess the current solid waste management practices in Mto Wa Mbu, a town and administrative ward in Tanzania's Arusha Region. By analyzing the waste management system in Mto Wa Mbu, this research aims to highlight policy shortcomings, both governmental and community-based, and offer insight into potential improvements. While Mto Wa Mbu has seen progress, largely driven by community-based organizations (CBOs) and private businesses, issues such as littering, open burning, and insufficient public waste disposal infrastructure persist. The paper concludes by proposing strategies for promoting a more circular economy within the village.

Keywords: Circular economy, Community Based Organizations (CBOs), Local municipalities, Open burning, Solid Waste Management (SWM)

Introduction

Solid Waste Management (SWM) in developing countries is a critical factor in safeguarding and improving public and environmental health. The urgency of effective SWM becomes evident when considering global projections: according to the United Nations Environment Programme (UNEP), annual solid waste generation is expected to rise from 2.1 billion tons in 2023 to 3.8 billion tons by 2050. UNEP also estimates the global direct cost of waste management at approximately USD 640.3 billion—this figure includes the hidden costs of pollution, poor health, and climate change resulting from inadequate waste disposal practices [12]. The scale and expense of the SWM crisis continue to grow, posing a considerable challenge for developing nations, many of which have only minimal or underdeveloped waste management systems [4]. When solid waste is neglected or improperly disposed of, public health and environmental quality deteriorate.

Poor SWM can have far-reaching consequences for health and the environment. For example, open burning releases harmful pollutants such as CO, CO_2, SO_2, NO_2, and PM_{10} into the atmosphere [16]. The release of solid waste into bodies of water contributes to global marine litter and environmental contamination [14]. Uncontrolled disposal also generates serious heavy metal pollution in water, soil, and plants [15].

In Arusha, Tanzania, projections indicate that solid waste generation will increase significantly by 2030 [11], raising concerns about the sustainability of current waste management practices. Due to limited budget allocations for SWM from the central government [1], waste management responsibilities are decentralized—each region is divided into districts, and districts into wards—leaving each jurisdiction to address its own challenges. The United Republic of Tanzania acknowledges its difficulties in providing adequate SWM support across all regions. As a result, local municipalities often rely on CBOs and private companies for waste management services, a framework envisioned by the Environmental Management Act (EMA) Part IX Sections 114-119 [2].

Mto Wa Mbu, an administrative ward in Arusha located near Lake Manyara, depends primarily on private businesses and Community-Based Organizations (CBOs) for its waste management. This small yet popular tourist destination serves as a gateway to several national parks. Consequently, beyond protecting public health and the environment, local stakeholders emphasize cleanliness to maintain the town's appeal to visitors. Although Mto Wa Mbu has made notable improvements in SWM over the years, this study found that the town continues to face persistent challenges, including littering, open burning, and limited adoption of circular economy practices.

This study gathered observations collected over a one-week period using a standardized survey checklist to assess the effectiveness of Mto Wa Mbu's waste management strategies. Supplemented by literature reviews of SWM in Arusha and beyond, the research aims to identify shortcomings and propose strategies for Mto Wa Mbu and other local municipalities to strengthen their SWM systems and expand opportunities. Ultimately, the discussion considers how local initiatives can play a

pivotal role in improving SWM while recognizing that sustained government support may be essential for achieving a long-term, sustainable circular economy [18]

Methods

Study Area

The observational data was collected within Mto Wa Mbu, beginning along the town's main road, T17, and extending into connecting streets. Four primary streets—Muungano Street, Vanga Street, Pangani Street, and Nyerere Avenue—were included in the survey. Data was also gathered from numerous unnamed residential paths branching off from T17.

To supplement the observations on solid waste management, the study incorporated an interview with a local stakeholder. The interview provided insights into Mto Wa Mbu's solid waste collection and waste transportation systems, as well as local initiatives aimed at promoting a more sustainable SWM framework.

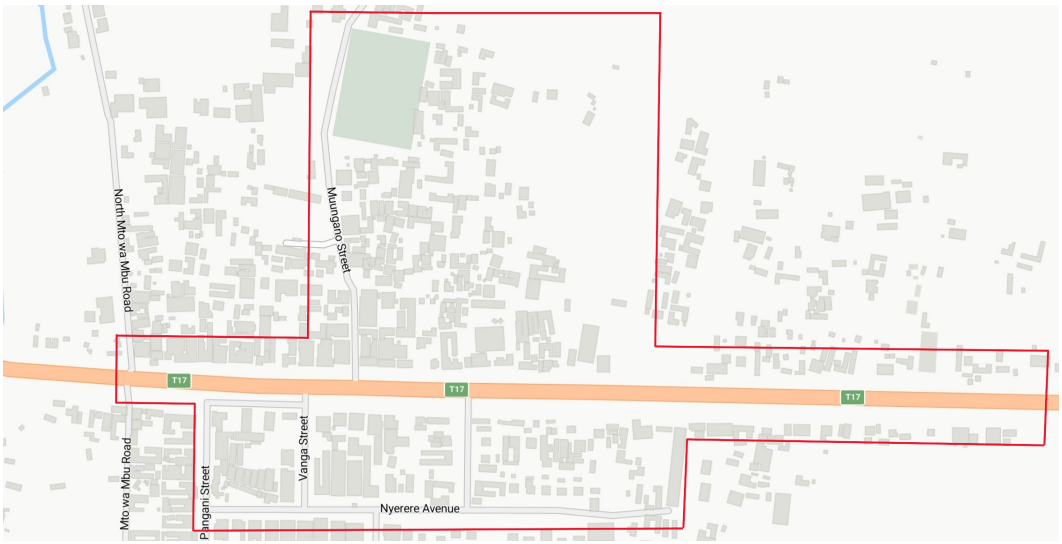

Figure 1. Map1 of the conducted study area in Mto Wa Mbu.

Observational Data Collection

Observational data was gathered over a one-week period in June 2025 to evaluate community behaviors related to solid waste management and mismanagement. The study area, shown in Fig. 1., included local food, electronics, general, and utility stores along T17, Mto Wa Mbu's main street, where both locals and tourists frequently shop. Observations also extended into the surrounding residential streets branching from T17. This area was selected because it serves as the town's central hub of activity and lies directly along T17, a highway connecting multiple national parks in the Arusha region and serving as a major route for tourists and Tanzanians.

Littering Practices, littering behaviors were recorded through field notes, documenting the amount and types of solid waste present. Common litter included plastic bottles, bottle caps, paper wrappings, and food scraps.

Open Burning, Instances of open burning were documented through field notes, noting both active burning sites and remnants of previous burning. Indicators included piles of ash, scorched vegetation, and partially burnt solid waste, often plastic.

Community Engagement, Community participation in SWM was assessed by observing public trash bins, composting, signage promoting waste cleanup, and other recycling initiatives. These indicators were used to evaluate local involvement in maintaining the town's cleanliness.

Literature Review

A literature review was conducted using several peer-reviewed publications to gain an understanding of effective SWM practices in developing countries worldwide. These publications also included studies on integrated waste management in sub-Saharan countries, with specific data from Tanzania. Additionally, studies focusing on waste management in the Arusha Region were reviewed to identify regional factors that may influence SWM in Mto Wa Mbu.

Results & Discussion

The data tables presented in this section represent the finalized version of the standardized observational checklist, which was completed for each street location within the Mto Wa Mbu study site. Data was recorded in qualitative amounts.

*Amount is defined as follows: *handful* (can fill one hand), *bagful* (can fill a standard plastic bag), *cartload* (can fill a cart measuring approximately 0.5 m^2), or *truckload* (amounts larger than a cartload) [8]. See Table 1.

The results of this study were derived by integrating qualitative data from the stakeholder interviews, the literature review, and the standardized observational checklist. These results assess the current methods of Mto Wa Mbu's SWM system and evaluate their effectiveness in relation to best practices for waste management in developing countries, as identified in the literature review.

Table 1. Observational Data by Location

Location	Data Collected	Description
T17	Public Waste Bins	1 waste bin, fair condition.
	Littering	Type & Amount: cartloads of plastic, bagsful of paper wrappings and food scraps. Items: plastic bottles, glass bottles, bottle caps, paper wrappings, food scraps.
	Waste Disposal Methods	Local Businesses piled filled trash bags in front. cartload of solid waste piled in front of few buildings.
	Waste Segregation	Plastic was separated from general waste (food scraps, glass, paper wrappings.)
	Local Recycling Initiatives	Old bags used as flowerpots. Glass bottles reused for new beverages. Scrap-business for reusing scrap metals.
	Evidence of Open Burning	None.
	Waterways Pollution	Littering accumulated in masses at drainage intersections. Visible bagsful of littering throughout open drainage system.
Muungano Street	Public Waste Bins	No waste bins on street.
	Littering	Type & Amount: bagsful of plastic, handfuls of paper wrappings. Items: plastic bottles, bottle caps, glass bottles.
	Waste Disposal Methods	cartloads of solid waste piled outside some homes, active open burning.
	Waste segregation	Not apparent.
	Local Recycling Initiatives	None.
	Evidence of Open Burning	3 separate piles of burnt SW and ashes
	Waterways Pollution	N/A
	Public Waste Bins	1 waste bin, fair condition

Location	Data Collected	Description
Vanga & Pangani Street	Littering	Type & Amount: bagsful of plastic, handfuls of paper wrappings and food scraps. Items: plastic bottles, plastic caps, paper wrappings
	Waste Disposal Methods	Piled trash bags in front of buildings.
	Waste Segregation	Plastic was separated from general waste.
	Local Recycling Initiatives	Reused old boxes and glass bottles. Vendors had waste bins in some stores.
	Evidence of Open Burning	None.
	Waterways Pollution	Handfuls of littering in open drainage system.
Residential Areas	Public Waste Bins	None.
	Littering	Type & Amount: cartloads of plastic, handfuls of paper and food scraps. Items: plastic bottles, paper wrappings, food scraps.
	Waste Disposal Methods	Piled waste outside homes, significant open burning practices, some filled trash bags.
	Waste Segregation	Not Apparent.
	Local Recycling Initiatives	None.
	Evidence of Open Burning	5 separate piles of burnt SW and ashes.
	Waterways Pollution	N/A
Nyerere Avenue	Public Waste Bins	None.
	Littering	Type & Amount: bagsful of plastic, handfuls of paper wrappings and food scraps Items: plastic bottles, bottle caps, paper wrappings, food scraps.
	Waste Disposal Methods	Not Apparent.
	Waste Segregation	Not Apparent.
	Local Recycling Initiatives	Truckload of banana peels for composting.
	Evidence of Open Burning	None.
	Waterways Pollution	Handfuls of littering in open drainage system.

Analysis of Results

The steps taken for SWM in Mto Wa Mbu are primarily driven by local stakeholders and a CBO in collaboration with private business efforts. The town has implemented positive initiatives in waste collection, as evidenced by the many local businesses along T17 that pile their trash bags for pickup. Waste is separated into distinct bags: those containing general waste (paper wrappings, glass, food scraps, etc.) and those containing plastics. The plastic-filled bags are purchased and collected by a private company for recycling and repurposing within their business operations. According to the local organizer and the literature review, the remaining waste bags are transported to the Muriet Landfill in Arusha [11], with trash collection occurring twice per month. Additionally, local stakeholders have organized town cleanups—though their frequency is unclear—to promote cleanliness and raise awareness of waste management. These activities indicate the presence of an *operational*, though still developing, *SWM system.*

An *operational SWM system* can be evaluated using the waste management strategy outlined in the study on Integrated Waste Management Policy and Legislation for African Countries. This-five-step framework ensures the development of a feasible waste management system for developing nations [19]. Figure 2 illustrates the program.

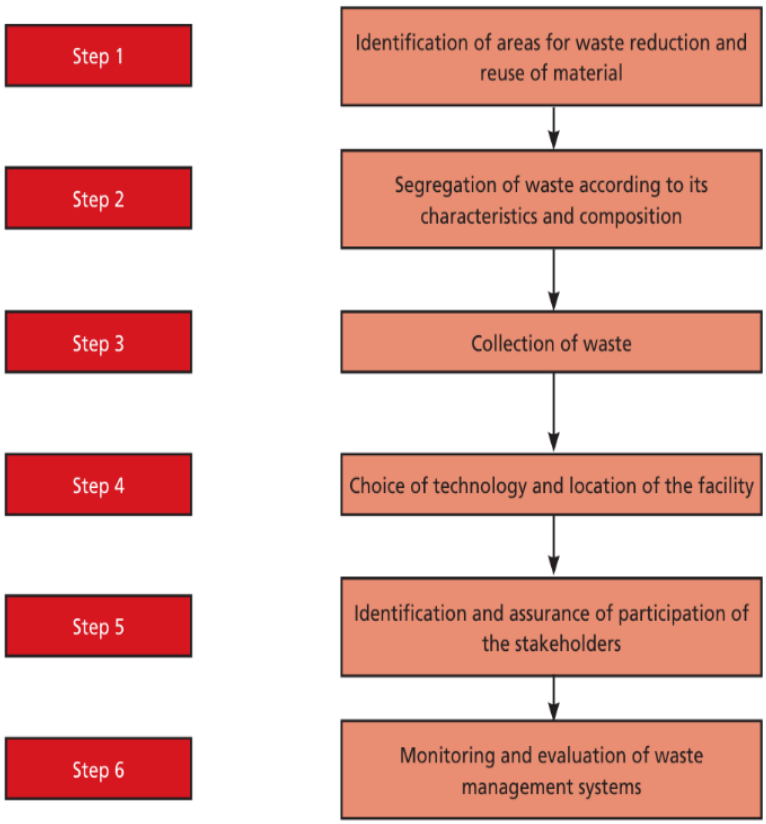

Figure 2. Steps2 of Waste Management Strategy (Source: D.D Basu, 201, CSE).

Step 1, The *Environmental Management (Prohibition of Plastic Carrier Bags and Plastic Bottle Cap Seals) Regulations, 2022* is a nationwide legislation passed by the Tanzanian government that imposes a total ban on plastic bags and plastic packaging [3]. This law has contributed to fulfilling the first step of the Waste Management Strategy in Mto Wa Mbu. Additionally, the town has made some effort to reuse metal scraps and compost biodegradable materials.

Step 2, Separating plastic from non-plastic waste prior to collection, along with composting banana peels and other biodegradable waste, contributes to the segregation of waste according to its characteristics and composition.

Step 3, An initiative by local stakeholders, in collaboration with a private recycling business, established a necessary waste collection system. While waste collection currently occurs twice a month in Mto Wa Mbu, the recommended frequency is once or twice per week for household waste and daily for market waste [10].

Step 4, The private recycling business fulfills Step 4 by using conventional recycling methods to process and reuse the plastic waste collected from Mto Wa Mbu.

Step 5, Participation of local stakeholders is vital for implementing a successful waste management plan [10]. In Mto Wa Mbu, stakeholders include households, small business owners, recyclers, and the informal sector. Participation is evident in various forms: the CBO that organizes trash pickup, the business owners who set out their waste, and the recycling company that collects it. However, many households in residential areas do not participate in formal collection, opting instead for open burning to dispose of their solid waste.

Step 6, Due to the decentralized nature of Mto Wa Mbu's solid waste management (SWM) system and the limited resources of the local government, monitoring and evaluation remain insufficient. This component is critical, as it enables authorities to gather data and improve overall management. Without data on waste generation, segregation rates, or collection efficiency, the system risks becoming ineffective.

Suggestions

In residential areas, open burning of waste remains common. This suggests that trash collection services may not be adequately reaching these parts of town, or that residents in these areas may lack awareness of the environmental and health consequences of open burning. Installing public waste bins throughout Mto Wa Mbu—paired with regular monitoring and collection—could significantly reduce littering and open burning. However, before implementing such infrastructure, it is crucial for a CBO or similar initiative to continue promoting waste management education across the town. Ensuring that residents understand the impacts of poor waste practices will help maximize the effectiveness of any new waste collection measures.

Additionally, Mto Wa Mbu's waste collection is closely interconnected with the Arusha region, as the town's trash is disposed of at the Muriet landfill site, located in Arusha city. This landfill receives solid waste from 24 of the 25 Arusha wards [11], with Mto Wa Mbu being one of the contributors. With the continuing development of Arusha region, the current daily waste generation of more than 550 tons is expected to increase significantly [1]. This should be a concern for local municipalities in Arusha City, because the current conventional landfill dumping is not a sustainable long-term practice and available space will run out [5]. This situation raises important questions about the need for more centralized and coordinated government assistance in waste management, including policies that promote and finance a circular economy.

Conclusion

Though Mto Wa Mbu has made significant progress toward developing an operational SWM system, challenges related to community awareness, open burning, littering, and dependence on a linear economy persist. The community has shown recognition of the importance of waste management, as demonstrated by proactive trash collection along T17, Vanga Street, Pangani Street, and Nyerere Avenue; however, there remains substantial room to improve sustainable SWM practices. As outlined in the recommendations, implementing public waste bins and strengthening community waste education could greatly enhance the town's SWM system if properly implemented.

Due to the time constraints and limited resources of this study, future research should focus on quantifying waste generation across all Mto Wa Mbu and conducting surveys on public awareness. These statistics could assist local CBOs and private businesses in shaping future SWM initiatives that foster job creation, economic growth, and improved waste infrastructure. Additionally, such data could strengthen transparency between CBOs and local municipalities, facilitating the development of more robust regional SWM policies.

Ultimately, SWM is not solely a local concern but a nationwide challenge that must be addressed to safeguard public health and protect the environment. Collecting and analyzing localized SWM data can help overcome current administrative and institutional barriers in Tanzania—particularly the lack of coordination between stakeholders and the local government, which limits the accessibility of necessary funding [1].

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Acknowledgement statement for the use of AI-Assisted Technologies: The work, writing, and content of this paper was all obtained through my own studies and research. I acknowledge the use of AI-assisted technology to proofread, and correct grammar for the final version of this study. Grammarly, 2025. (v1.2.183.1724).

Consilience: The Journal of Sustainable Development
Iss. 28 (2026)

CONSILIENCE
THE JOURNAL OF SUSTAINABLE DEVELOPMENT

Campus as a Carbon Sink: The Impact of Land Cover and Compaction on Soil Carbon Sequestration at Elon University

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Abstract

Soils are a major carbon sink, and as atmospheric carbon emissions continue to increase around the world, attention is being turned to soils as a possible way to offset these emissions. For institutions like colleges and universities that manage significant acreage and are increasingly seeking avenues toward carbon neutrality, quantifying and enhancing the amount of carbon held in campus soil may be a valuable addition to existing sustainability efforts. This study investigates how land cover and soil compaction affect soil carbon sequestration on a college campus in the Southeastern U.S. Areas of different land covers in one campus neighborhood were mapped using GIS software to determine predominant landscaping conditions. Grassy lawns covered 67.4% of the study area, perennial beds covered 22.9%, and annual beds covered 2.1%, making up the vast majority of permeable surface area. Compaction measurements and soil samples were taken from randomly selected points within each of these three land cover types. Soil samples were analyzed using Loss-on-Ignition (LOI) techniques to determine the percentage of soil organic carbon (SOC) by mass. Findings showed that compaction is strongly correlated with land cover, prohibiting the distinction between the impact of land cover vs. compaction on SOC content. Perennial beds were moderately compacted and contain more SOC than grassy lawns (average 8.02% vs. 6.37%) which were highly compacted. Annual beds were minimally compacted and showed the highest average SOC values of 23.97%, likely due to large inputs of compost rather than long-term biological soil carbon sequestration. The results of this study suggest that conversion of grassy lawns into perennial plant beds would increase SOC sequestration potential on campus, thereby contributing to university carbon neutrality goals by sequestering atmospheric carbon in the ground.

Keywords: Soil carbon sequestration, Land cover, Compaction, GIS

Introduction

As carbon emissions continue to increase around the world, attention is being turned to soils as a potential way to mitigate these emissions (Amelung et al., 2020, Longbottom, 2022, Rumpel et al., 2020). Serving as an important carbon sink (a natural reservoir that can hold and absorb carbon from the atmosphere), soils may currently store twice as much carbon as the atmosphere and vegetation combined (Friedlingstein et al., 2020). Soils are able to sequester carbon from the atmosphere and store it underground, entering the soil through processes like the decomposition of plant and animal matter as well as through eroded carbon deposition (Longbottom, 2022). Carbon can exit the soil through leaching, erosion, and microbial decomposition which converts the carbon to carbon dioxide gas (Longbottom, 2022). Soil organic carbon (SOC), which represents the current balance between outputs and inputs to a system (Longbottom, 2022), is a key measure of soil health (Roper et al., 2019). Maintaining soils' ability to sequester organic carbon in landscaped and managed spaces is crucial in the face of anthropogenic climate change, since soils cycle carbon at much slower rates than the other carbon sinks (Dutta et al., 2019, Longbottom, 2022, Paustian et al., 2016, Schmidt et al., 2011).

Colleges and universities play a unique role in promoting sustainable practices. In recent years, a rising number of these institutions have made commitments to become more sustainable, including carbon neutrality goals (Myers, 2021; Sen et al., 2021). Oftentimes, colleges and universities control a significant amount of acreage and using sustainable landscaping practices is one potential avenue to offset carbon emissions. As a result, several prior studies have examined factors influencing soil carbon sequestration on college and university campuses in India (Saha & Handique, 2022), Massachusetts (Hundertmark et al., 2021), and Minnesota (Black et al., 2014). Land cover exerted an outsized impact on SOC in these studies: Lawns were consistently identified as problematic, demonstrating the lowest SOC content throughout the annual cycle (Saha & Handique, 2022) and even acting as net sources of carbon emissions (Hundertmark et al., 2021). Recommendations included increasing tree canopy cover (Hundertmark et al., 2021; Saha & Handique, 2022), reducing mulch applications (Hundertmark et al., 2021), and using native plants for ground cover and in beds near buildings (Saha & Handique, 2022). While these recommendations are likely to translate well across contexts, the influence of land cover types in other regions and climates (such as the warm, wet southeastern U.S.) should be verified. Furthermore, since perennial plants frequently exhibit different depths of root penetration (Bárcena et al., 2014), and annual (or even seasonal) plantings require frequent soil disturbance which may encourage the oxidation of carbon and disruption of soil structure (Haddaway et al., 2017), additional investigation is needed into the impacts of different types of ornamental plantings.

A second factor that has been examined more closely for its impact on campus soil carbon sequestration is compaction (Savina, personal communication, July 13, 2022; Black et al., 2014). Soil compaction has been well researched as a factor reducing crop production in agricultural settings (Hamza & Anderson, 2005) by reducing water infiltration (Gregory et al., 2006), limiting root penetration, root decay, and microbial activity around roots (Hamza & Anderson, 2005, Black et al., 2014), as well as root

exudation which would encourage microbial activity (Longbottom, 2022). High levels of soil compaction resulting from construction have even been shown to reduce the growth of woody plants (Alberty et al., 1984). Therefore, compaction impacts soil carbon sequestration on college campuses as well.

Prior results regarding the prevalence of compaction and its impact on SOC on college campuses have varied. Saha & Handique (2022) measured bulk density as a measure of compaction on the campus of Tezpur University in India, and did not identify any "extreme soil compaction" that would limit root growth. However, Black and colleagues (2014) identified compaction from foot traffic, vehicle traffic, and construction on the campus of Carleton College in Minnesota as a key soil disturbance with the potential to limit carbon storage potential (Black et al., 2014), suggesting the need for future campus studies to further investigate this variable (M. Savina, personal communication, July 13, 2022).

While both land cover and soil compaction have been demonstrated to impact SOC on college campuses, prior work has yet to address the interrelationships among them to inform holistic recommendations for campus landscaping. This study seeks to investigate the correlation between land cover, soil compaction, and SOC content on Elon University's campus. We break this set of interrelationships down using the following three research questions:

1. Is there a correlation between land cover and SOC content?
2. Is there a correlation between soil compaction and SOC content?
3. Is there a correlation between land cover and soil compaction?

We hypothesized that areas with more foot traffic such as grassy lawns would be more highly compacted, decreasing soil biological activity and therefore SOC content. Conversely, we hypothesized that perennial beds, which discourage foot traffic compared to grassy lawns and incorporate larger plants with more extensive root systems than annual beds, would be both less compacted and have the highest SOC content.

Materials and Methods

Study Context and Overview

Elon University's campus, located in central North Carolina, has been repeatedly awarded one of the most beautiful campuses in the country by the Princeton Review (Covington 2019), and has adopted a carbon neutrality goal of 2037 (Elon University, 2022). The university landscaping crews work on maintaining the grounds year-round. Though some sustainable practices are implemented, there is currently no mention of landscaping in the university's greenhouse gas emissions report aside from a goal of planting more trees (Elon University, 2022). The campus is located in the Piedmont bioregion, with deeply weathered ultisols (red clay soils) resulting from the warm, relatively wet climate of the area. The research focused on

the Historic Neighborhood, the oldest area of campus (first constructed in 1889). This research was completed in four stages: GIS mapping, field sampling, lab analysis, and statistical analysis, each described in detail below.

GIS Mapping Methods

The study area was first mapped using Esri's ArcMap software. Aerial imagery of campus was digitized, and polygons were created to represent the non-impervious surfaces. Using a combination of aerial imagery examination with in-person observations of the study area on the ground, each polygon was then assigned an attribute representing their land cover: grassy lawns, perennial beds, annual beds, mulched beds, and bare soil. Grassy lawns are defined as turf-grass lawns mowed and maintained regularly throughout the year by university landscaping crews. Perennial beds are defined as areas of vegetation dominated by perennial vegetation (e.g., shrubs, perennial herbs, etc) that is not replaced on a regular basis by landscaping crews. Annual beds are defined as plant beds dominated by annual plants (often flowers) in which the university landscaping crew changes the vegetation seasonally throughout the year. Mulched beds are defined as beds that have been mulched with either pine straw or wood chips but where no vegetation was growing at the time of the study. Bare soil is defined as areas where nothing was growing, and soil was exposed at the surface. Most commonly, bare soil areas were within grassy lawns, and were likely the result of heavy foot and vehicle traffic or grass seed failure.

After the initial mapping stage, the GIS map was ground-truthed in order to determine the average difference between the GIS map polygon locations and the corresponding features of the study area. 23 polygons (20% of the total polygons created) that were clearly visible on the aerial imagery were chosen and the ArcMap measurement tool was used to measure their dimensions as represented on the map. This same width was then measured in the field using a meter tape. The absolute value of the actual dimension minus the map dimension was taken and these values were averaged for all polygons to determine the average error margin in meters.

In ArcMap, all the polygons were then grouped together by land cover type and the random point generator tool was used to determine field sampling sites. The number of sites was roughly proportional to the amount of area in that land cover type. Grassy lawns were given 40 sample sites, perennial beds were given 20 sample sites, and a minimum sample threshold of ten was set for the remaining three land cover types. Each point was given a unique ID and the latitude and longitude was recorded in the attribute table.

Field Sampling

Soil compaction readings and probe cores at 33 randomly selected sampling sites were taken in January of 2023. Sampling was done on a day where there had not been freezing temperatures or precipitation for at least 48 h prior. Field sampling was performed for a subset of sites in grassy lawns (n=11), perennial beds (n=12), and annual beds (n=10) because these land cover types were hypothesized to have the greatest differences based on prior literature. A cell phone GPS app and landmarks

were used to confidently locate the sample sites. At each site, a digital soil penetrometer was used to take three compaction readings within 10-cm of one another, to account for hyperlocal soil variation. A 10-cm soil core was then taken, bagged, and was stored at freezing temperatures until lab analysis.

Lab Analysis

The soil samples were homogenized using a mortar and pestle to break up soil aggregates (large grains were not pulverized in the process). A sub-sample (5-6 g) of each sample was then placed in a ceramic crucible and dried overnight at 105 °C and then weighed. Loss on ignition analysis was performed at 360°C for two hours to allow for the organic carbon to be combusted while limiting the dewatering of clay minerals (Schulte et al., 1991). Samples were weighed again after combustion and the difference in mass was calculated to determine the amount of soil organic carbon originally present in the sample.

Statistical Analysis

For each sample site, the land cover type, average of three compaction values, and percent organic carbon determined by LOI were entered into IBM SPSS v28. Soil compaction and land cover were compared using a one-way ANOVA test to account for the one continuous outcome variable and the one continuous predictor variable with three different entities. Land cover and percent SOC were compared using a multiple linear regression to account for the one continuous outcome variable and the three different categorical predictor types. Compaction and percent SOC were compared using a Pearson correlation to account for the one continuous outcome variable and one continuous predictor variable. Finally, an additional T-test was run to compare the percent SOC of just two land cover types, grassy lawns and perennial beds. Effect size measures were calculated to determine the scale of differences in compaction and SOC between land cover types (Sink & Mvududu, 2010, Sullivan & Feinn, 2012). An eta-squared value, Cohen's f-squared value, and Cohen's d effect size were calculated to accompany the ANOVA test, multiple linear regression, and T-test respectively.

Results

The study area represented 13.22 ac of the university's 690-ac campus. Overall, the study area was 53,506 m² with 43% being impervious surfaces (buildings, roads, sidewalks). Of the remaining 30,243 m² of non-impervious area, the study area was mostly grassy lawns at 67%, followed by perennial beds at 23%, mulched beds at 6%, and annual beds and bare soil both at 2% (Figure 1). The ground truthing process showed an average error between real-world dimensions and map dimensions of 0.4 m.

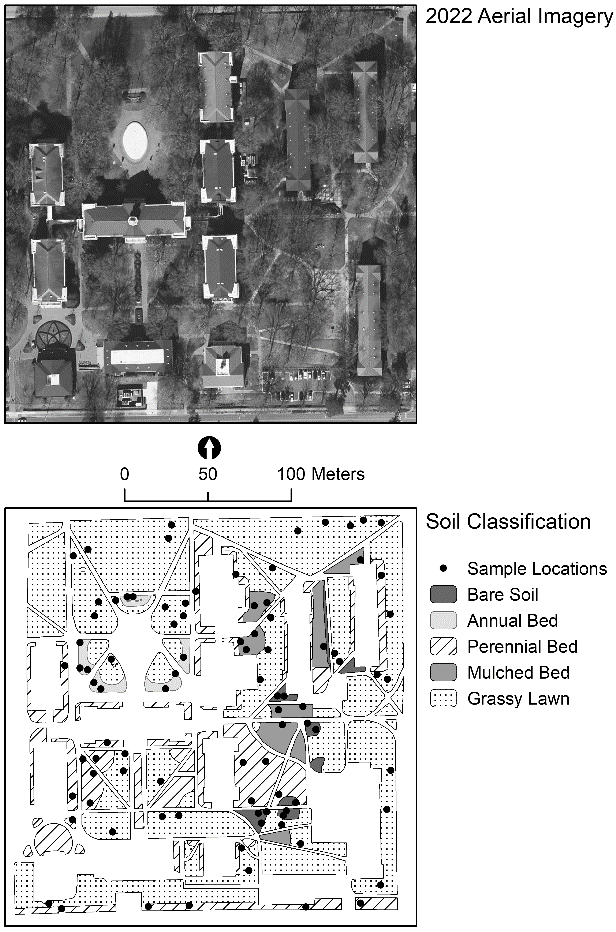

Figure 1. Map of the study area

RQ 1: Is there a correlation between land cover and SOC content?

Loss-on-ignition analysis showed the average SOC to be 6.37% for grassy lawns, 8.02% for perennial beds, and 23.97% for annual beds (Table 1). Grassy lawns ranged from 4.34-9.22% SOC. Perennial beds ranged from 4.93-11.54% SOC. Annual beds ranged from 18.07-27.95% SOC (Table 1). Multiple linear regression showed a very strong correlation found between percent SOC and land cover at the 95% confidence interval (R^2=0.719, Cohen's f^2 =2.56) (Figure 2). Because their SOC ranges overlapped, an additional analysis was run comparing the SOC of grassy lawns and perennial beds. A two-sample t-test at 95% confidence showed a statistically significant difference in SOC content (p=0.042, Cohen's d effect size= 0.43) (Figure 3).

Table 1. Soil SOC content results from LOI analysis of samples

Land Cover	Average % SOC	Min % SOC	Max % SOC
Grassy Lawns	6.37	4.34	9.22
Perennial Beds	8.02	4.93	11.54
Annual Beds	23.97	18.07	27.95

Figure 2. Percent SOC by land cover

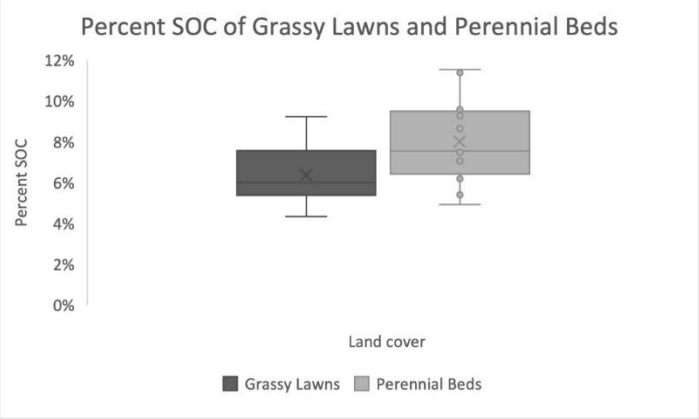

Figure 3. Percent SOC of grassy lawns vs. perennial beds

RQ 2: Is there a correlation between soil compaction and SOC content?

A Pearson correlation showed a strong negative correlation between soil compaction and percent SOC (R= -0.730, p<0.001) (Figure 4).

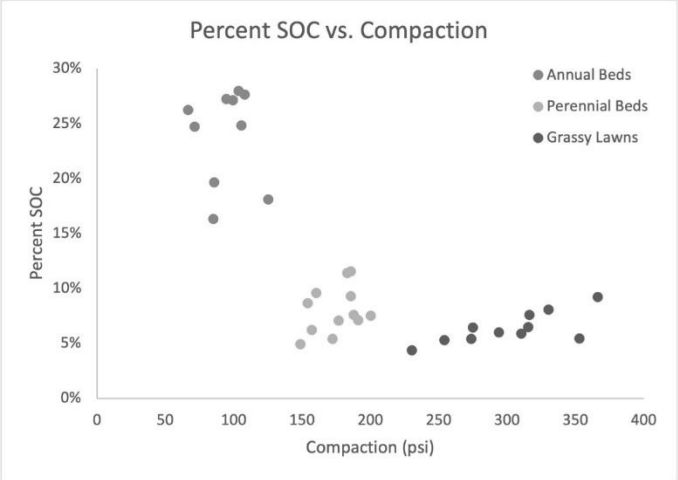

Figure 4. The correlation between percent SOC content and soil compaction

RQ 3: Is there a correlation between land cover and soil compaction on Elon's campus?

Field sampling showed the average compaction level to be 301.69 psi for grassy lawns, 175.19 psi for perennial beds, and 94.53 psi for annual beds (Table 2). Grassy lawn compaction ranged from 230.33 to 366.33 psi. Perennial bed compaction ranged from 148.66 to 200.33 psi. Annual bed compaction ranged from 66.66 to 125.33 psi (Table 2). A one-way ANOVA statistical analysis at 95% confidence showed there is a very strong correlation between soil compaction and land cover ($p<0.001$, $\eta^2=0.910$) (Figure 5).

Table 2. Soil compaction levels from field sampling

Land Cover	**Average Compaction (psi)**	**Min Compaction (psi)**	**Max Compaction (psi)**
Grassy Lawns	301.69	230.33	366.33
Perennial Beds	175.19	148.66	200.33
Annual Beds	94.53	66.66	125.33

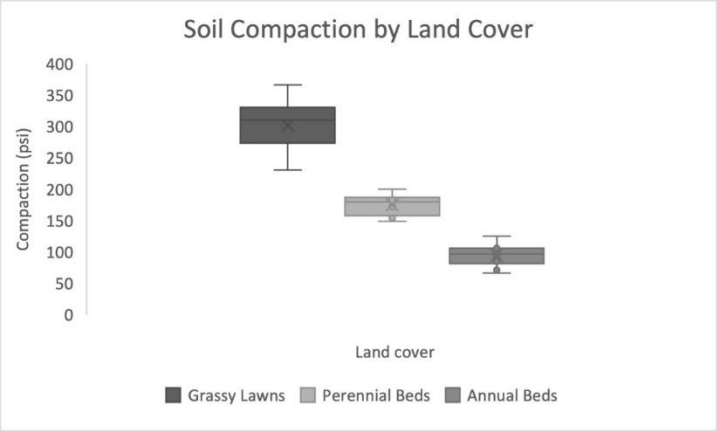

Figure 5. Soil compaction by land cover

Discussion

RQ 1: Land cover and SOC content

Each land cover type at Elon University was statistically different from each other land cover type in terms of SOC (Figure 2). Grassy lawns contained the least SOC. When the grassy lawns at Elon University are mowed, the grass clippings are removed and composted off campus. The same is done to the leaves that fall on campus during autumn. These are two examples of natural carbon inputs that this system is not receiving due to management practices (Longbottom, 2022). The removal of organic material from the soil's surface before decomposition is likely contributing to the low SOC content of grassy lawns. These findings are consistent with Tezpur University where gardens and parks contained the least amount of SOC (Saha & Handique, 2022). This is also similar to Boston University where researchers went further to determine that lawns on their campus were actually carbon sources as opposed to carbon sinks due to high respiration rates (Hundertmark et al., 2021). Further studies at Elon University should seek to quantify carbon respiration and carbon emissions from landscaping practices in order to determine if the grassy lawns could potentially be a carbon source here as well. Measuring these additional carbon outputs from the system would eliminate some of the uncertainty surrounding the effect of landscape processes on sequestration and inform better mitigation strategies (Paustian et al., 2016).

Contrary to our hypothesis, the land cover with the highest SOC content was annual beds. Throughout the year, these beds regularly have mulch and compost applied directly to the soil, both of which are high in organic matter and artificially increase the overall SOC content of the soil. Plants in these beds are removed and replaced seasonally, so there is little time for them to establish extensive root systems. Therefore, the high SOC percent found in annual beds is likely attributable to artificial carbon inputs and not natural, long-term carbon sequestration processes (Hamza & Anderson, 2005, Black et al., 2014). Future work should seek to quantify these inputs and isolate them from natural, biological carbon additions to the soil.

Because the high SOC content of annual beds is suspected to be artificial, further analysis was done directly comparing grassy lawns and perennial beds. Perennial beds had a significantly higher SOC content than grassy lawns (Figure 3). We therefore recommend that Elon University convert lawn areas to perennial beds to increase the overall SOC content within campus soils. Even the conversion of small areas can have a crucial impact on the overall sequestration levels especially when scaled up to the entire campus (Hundertmark et al., 2021, Rumpel et al., 2020, Saha & Handique, 2022). Perennial beds also require less maintenance and inputs than annual beds, so increasing their coverage on campus would decrease the carbon emissions that are created by landscaping tools and vehicles.

RQ 2: Soil compaction and SOC content

Just as soil compaction has been shown to affect crop production (Hamza & Anderson, 2005) and reduce woody plant growth (Alberty et al., 1984), this study suggests compaction decreases SOC content as well. Soil compaction had a strong, negative correlation with percent SOC so as the soils sampled became more compact, the SOC content decreased significantly (Figure 4). The highly compacted soil areas are likely suffering from reduced water infiltration (Gregory et al., 2006), limited root penetration, root decay, microbial activity around roots (Hamza & Anderson, 2005, Savina et al., 2015) and reduced root exudation (Longbottom, 2022). While compaction in on-campus soils may be inevitable in some locations due to construction vehicle traffic, and foot traffic (Black et al., 2014), reduced compaction values found in perennial beds in this study suggest they meaningfully deter and reduce those sources of compaction as compared to grassy lawn areas, helping to sustain the soil's carbon sequestration potential.

RQ 3: Correlation between land cover and soil compaction

The three land cover types sampled each had unique compaction ranges which were significantly different from one another (Figure 5). Land cover types like grassy lawns, which showed the greatest compaction values, are likely more susceptible to sources of campus soil compaction such as foot traffic, vehicle traffic, and construction (Black et al., 2014) because they present minimal physical impediment to movement across them. Grassy lawns are mowed frequently with industrial-grade mowers, which may be further contributing to compaction.

In contrast, the soil within perennial beds is protected from foot traffic above by larger vegetation (e.g, bushes and shrubs) and the vegetation there does not require mowing. This greatly limits the forces on top of the soil that can contribute to excess compaction, leaving perennial beds less compacted than grassy lawns. Similarly, annual beds do not require mowing and are rarely walked on due to their positions against walls and at the margins of campus, as well as their mounded topography (likely created by frequent compost additions). When the annual vegetation is replaced in the fall and spring, the beds are also tilled, which undoes any compaction that may have occurred. This process results in annual beds being the least compact, with loose soil compared to grassy lawns. Therefore, plants in these beds may be more effective at encouraging microbial activity via root exudates than in highly compacted grassy lawns

(Longbottom, 2022). Nonetheless, frequent disturbance of annual beds via tilling as well as the removal of vegetation and their root systems likely limit any long-term carbon sequestration by annual plants (Longbottom, 2022). The significantly greater oxygenation of the soil allowed by its minimal compaction and frequent tillage likely encourages higher rates of decay of organic carbon (Longbottom, 2022) that is currently obscured by frequent compost additions from outside the system. Thus, perennial beds may represent a "happy-medium" in which root penetration and exudates are permitted, and decay rates are moderate.

The strong correlation between land cover and soil compaction means that it is difficult to isolate the effect of these two variables on SOC at this location. A similar interrelationship is likely to occur on other college and university campuses, where land cover influences compaction and the two together then influence SOC. Ultimately, we suggest that they must be considered together in considering sustainable landscaping practices.

Summary and Conclusion

When managed sustainably, landscaped areas on college campuses can act as carbon sinks, sequestering atmospheric carbon underground and helping to offset university emissions. Land cover type and soil compaction are strongly correlated, and together exert a combined influence on soil carbon content. At Elon University, perennial beds were less compacted and contained more carbon than grassy lawns, and required less disturbance and artificial inputs of carbon than annual beds. Therefore, we recommend that the university convert areas of grassy lawns into perennial beds to increase soil carbon sequestration. This conversion will also decrease carbon emissions from landscaping tools and vehicles because perennial beds require less maintenance than grassy lawns. Small landscaping changes such as these can make a significant difference in carbon sequestration potential, making campuses more sustainable and helping them to achieve their carbon neutrality goals.

Acknowledgements

The authors are grateful to Dr. Ryan Kirk for his contribution to the GIS portion of this research. Additionally, this work was recognized by the G. Herbert Stout Award for Innovative Student Papers in GIS. This research was also supported by Dr. Amanda Chunco, Dr. Jen Hamel, Dr. Justin Clar, and the Elon Environmental Studies Department. We thank all those involved for their valuable input and guidance throughout this project.

Disclosure of Interest

The authors report there are no competing interests to declare.

Declaration of Funding

This article was made possible by the Elon University Center for Undergraduate Research and the Glen Raven Endowed Grant.

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The top image shows the aerial imagery of the study area in the Historic Neighborhood at Elon University. The bottom image shows the study area classified by land cover, including points representing soil sampling locations.

This box and whisker plot shows the percent SOC content for each land cover type based on the results of the LOI analysis. There was a very strong correlation found between percent SOC and land cover using a multiple linear regression statistical analysis at 95% (R^2 value=0.719, Cohen's f^2 =2.56).

This box and whisker plot provides a direct comparison of percent SOC content between grassy lawns and perennial bed land covers. A two-sample t-test at 95% confidence showed a statistically significant difference in SOC content (p=0.042, Cohen's d effect size= 0.43).

This scatterplot shows the correlation between percent SOC content and soil compaction. The classification of land over is also shown on the plot. A Pearson correlation showed a strong negative correlation between soil compaction and percent SOC (R= -0.730, p<0.001).

This box and whisker plot shows the soil compaction values measured during field sampling for the different land covers. A one-way ANOVA statistical analysis at 95% confidence showed there is a very strong correlation between soil compaction and land cover (p<0.001, η^2=0.910).

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Consilience: The Journal of Sustainable Development
Iss. 28 (2026)

CONSILIENCE
THE JOURNAL OF SUSTAINABLE DEVELOPMENT

Rethinking the Impact of Large-Scale Tree-Planting on Soil Quality for the Chronically Poor

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Abstract

This paper examines how large-scale tree-planting strategies shape soil quality (SQ) and how SQ, in turn, affects the world's poorest communities. While afforestation and large-scale tree-planting efforts have been promoted as low-cost, climate-friendly solutions, their implications for SQ are complex and yield mixed results since SQ characteristics are largely context-specific. Nature-based solutions are only effective if they work for the people who live with them every day. However, when large-scale tree-planting degrades SQ and local livelihoods, these efforts fail to be "solutions" and instead widen the poverty gap. Using a systematic literature review of peer-reviewed empirical studies, this paper builds on previous unpublished research demonstrating that tree planting yields context-dependent soil quality outcomes and examines how poor soils create and perpetuate poverty traps. The paper then evaluates inorganic fertilization as a potential intervention but finds that, despite its effectiveness, cost barriers make it unaffordable for the communities that need it most. In response, this research identifies improved tree fallows, as well as the invasive species and hybrid fruit-bearing variants, as promising alternatives for soil restoration. In addition, these approaches require minimal cash investment, reduce labor demands, and provide valuable byproducts, making them accessible to even chronically poor farmers. The paper argues that a "business as usual" approach to large-scale tree-planting without regard to soil quality risks creating poverty traps for low-income farmers, and that improved, invasive, and hybrid fruit-bearing fallows offer a more people-centered, low-cash approach to restoring soils while contributing to reforestation goals.

Author's Note

Look at a coffee cup or an airline ticket, and you are likely to see something along the lines of "one-hundred cups plants one tree," or "this ticket helps plant trees." Tree planting is everywhere. However, large-scale tree planting is not the simple solution it is often advertised to be. While much of the world's carbon emissions originate in the Global North, many large-scale tree-planting initiatives are

implemented in the Global South, where their social and ecological consequences are most strongly felt. My professor, Vijay Ramprasad, inspired me to write this paper. In class, Ramprasad challenged us to approach environmental issues by thinking first about the people these problems impact. Case studies such as Aggarwal (2021) demonstrated how forest carbon projects in developing countries damage local livelihoods, and because these methods don't work for the people, they uproot the trees, leading to poor survival rates and ineffective carbon sequestration. This inspired me to look at other ways tree-planting affects livelihoods and the environment, and I found soil quality to be among the most important. Building on earlier unpublished research on soil quality, this paper adopts a people-centered approach and argues that soil metrics are meaningless if they are detached from livelihoods, health, and long-term well-being.

Keywords: Soil quality, Tree fallowing, Chronic poverty, Poverty traps, Soil degradation

Introduction

As large-scale tree-planting becomes an increasingly popular strategy to combat the effects of climate change through carbon sequestration, the question of how these practices affect SQ has become pressing. Though not specifically mentioned, SQ is an indirect focus of multiple United Nations Sustainable Development Goals (Helming et al., 2018). One reason is that the SDGs' number one goal is to end poverty in all its forms, and current research shows a strong link between economic status and soil quality (Barrett and Bevis, 2015). Because the world's poorest communities depend directly on degraded soils for food, fuel, income, and livelihoods, fully understanding the complex relationship between poverty and SQ, and then creating policy based on these findings, is important to preserving these communities' well-being (Barrett and Bevis, 2015). Furthermore, investigating SQ and its relationship to poverty is a pressing issue; soil degraded by deforestation has proven difficult to restore. This is problematic because soil-improving management options typically are advantageous only after long periods of time (Helming et al. 2018). Because of this dynamic, scientific and academic communities must set a high standard regarding large-scale tree-planting and SQ. Building upon previous unpublished research demonstrating that tree planting yields context-dependent soil quality outcomes, this paper examines the risks of large-scale tree planting, which may create poverty traps for the world's poorest communities through soil degradation. The paper evaluates inorganic fertilization as a potential soil restoration strategy, then investigates improved, invasive, and hybrid fruit-bearing fallows as alternative approaches that may better align with smallholder economic limitations.

Methodology

This paper used a systematic literature review methodology to examine the relationships between tree planting, SQ, and chronic poverty. The research is a continuation of unpublished work that analysed the impacts of tree planting on SQ across various contexts.

Literature Search Strategy: Research articles were identified through multiple academic databases, including Google Scholar, JSTOR, Web of Science, and ScienceDirect. Search terms included combinations of: "soil quality," "soil fertility," "poverty traps," "tree planting," "afforestation," "agroforestry," "tree fallows," and "soil degradation."

Selection Criteria: Sources were selected based on the following criteria: (1) peer-reviewed journal articles and reports from reputable institutions; (2) focus on soil-poverty relationships, agricultural interventions, or agroforestry practices; (3) empirical evidence or well-supported theoretical frameworks. Both quantitative and qualitative studies were included to capture multiple methodological approaches.

Literature Review

4.1 General Links Between Soil and Poverty

Despite SQ's direct ties to poverty, it is often overlooked in low-income farming communities. In addition, a growing body of research has found "strong links" between chronic poverty and soil (Barrett and Bevis, 2015). Further, it is difficult to directly "feel" the effects of long-term soil degradation, as it occurs gradually, sometimes over many years (Warui, 2024). Nevertheless, evidence suggests that economic status and SQ are linked and can even reinforce one another (Barrett and Bevis, 2015). Since many of the world's poorest communities rely on degraded or degrading land to support their agricultural livelihoods, these people are at risk of becoming victims of potential poverty traps due to a lack of soil fertility. In this way, planting trees on smallholder land may jeopardize and trap these pastoralists into chronic poverty.

4.2 Poverty Traps

Soil can create poverty traps in numerous ways. Soil is a limiting factor that directly constrains agricultural productivity and incomes derived from agriculture (Barrett and Bevis, 2015). Therefore, a vicious cycle can occur in which smallholders working on poor soils generate low agricultural incomes in the present, leaving them without sufficient resources to invest in soil improvements that could benefit future yields (Barrett and Bevis, 2015). Further, even if smallholders can provide enough capital to invest in SQ, some land has become so degraded that such investments would yield no return, further reinforcing the poverty trap (Barrett and Bevis, 2015). Because degrading practices, such as large-scale tree planting, alter soil fertility, tree-planting practices may pose a problem for farmers who buy, inherit, or rent land with a history of large-scale tree planting.

The poverty trap can also extend to affect the broader development of human settlements and infrastructure. Lower-fertility soils typically cannot support high-density human settlement, meaning that small, low-density settlements are the norm. This increases the per-capita cost for governments to provide essential infrastructure such as roads, electricity, and telecommunications, making it harder to sell produce, maintain health, education, and other important benefits that come with high-density populations (Barrett and Bevis, 2015). Beyond infrastructure, SQ-induced poverty traps can also threaten human health and productivity.

The effects of SQ may harm human health, further reinforcing poverty traps. Micronutrients derived solely from soil may be deficient in degraded soils, leading to dietary mineral deficiencies and detrimental human health outcomes (Barrett and Bevis, 2015). Additionally, if modern infrastructure (roads, electricity, and telecommunications) is limited due to low population density, households become more dependent on locally grown produce, which could make specific minerals hard to come by (Barrett and Bevis, 2015). Further, when non-palatable foreign tree saplings are planted in areas where pastoralists herd their livestock, these plants can sicken or kill livestock, reducing herd productivity and increasing livelihood vulnerability

(Ramprasad et al., 2020). When herd productivity decreases, this may lead to a deficiency in nutrients and protein. If members of a household have a deficiency in essential nutrients, they may become susceptible to illness and disease, which may reduce or eliminate their ability to continue contributing to household income or well-being. Further, lack of nutrients at a young age can affect adult labor productivity over the long term (Barrett and Bevis, 2015). One example in Xinjiang, China, saw a 50% decrease in infant mortality after an iodine micronutrient was introduced into the soil. This demonstrates the role that SQ plays in human well-being and livelihoods (Barrett and Bevis, 2015). These soil-based mineral deficiencies contribute to the SQ poverty trap since much of the world's poorest have livelihoods that depend on physical labor, and when they are unable to reach their full earnings potential due to compromised health and development, they fall behind. In addition to health and nutrition concerns, soil poverty can also contribute to ecological risk and environmental shocks.

4.3 Soils and Risk

Beyond the direct yield effects of soil in agriculture, soils have been shown to influence how well smallholders recover from environmental and economic shocks (Barrett and Bevis, 2015). For example, poor soil fertility may make a farmer's field more susceptible to drought, pests, and disease. In particular, Barrett and Bevis's 2015 study examined how parasitic weeds, particularly Striga, thrive in low-nutrient soil conditions. This poses yet another challenge to low-income farmers, which in turn creates more labor, more strain, and susceptibility to falling into a poverty trap. In addition, poor farmers working in susceptible soils are less likely to invest in improvements or adopt new farming strategies because they cannot afford potential losses if yields are diminished. In contrast, farmers working fertile fields face lower crop yield risk, allowing them to pursue higher-return agricultural activities (Barrett and Bevis, 2015). This difference in susceptibility between poor and healthy soils demonstrates how soils influence future investment. However, many of the world's poorest communities depend on degraded lands for their agricultural livelihoods (Barrett and Bevis, 2015). Degraded soil, in turn, makes agricultural pursuits and future investments increasingly less fruitful. Given the numerous ways in which degraded soils can trap people in poverty, intervention is necessary to break these cycles.

4.4 Inorganic Soil Fertilization

Given that SQ holds importance in poverty alleviation, inorganic fertilization of degraded soils seems like a simple solution. Further, inorganic fertilization is a popular approach to agriculture, especially in first-world countries where nearly 100% of farmland uses inorganic fertilization (Kim and Bevis, 2019). However, research has shown that inorganic soil fertilization is not a widespread approach in much of the global south; less than one-third of sub-Saharan African farmers use inorganic fertilizer (Kim and Bevis, 2019). Additionally, one-third of the world's soils are degraded, with over 40% located in Africa (Warui, 2024). This demonstrates that fertilizer adoption remains low in the areas that need it the most. This is because inorganic fertilizer is expensive in developing countries (Kim and Bevis, 2019). The price may exclude participants who want to improve SQ but cannot afford it. Additionally, inorganic fertilizers may increase operating costs but not produce the necessary profitability,

further jeopardizing poor communities and forcing them into poverty traps. For these reasons, inorganic fertilizers do not work for the world's poorest communities. This is problematic because many of the world's poorest people disproportionately live in areas with degraded soil (Kim and Bevis, 2019). Given the financial barriers to chemical fertilization, one method involving tree-planting has emerged as a potentially more accessible alternative that works for the world's poorest while improving SQ in cash-strapped environments.

Main Findings

5.1 The Improved Fallow

The improved tree fallow is a cost-effective method in which fast-growing nitrogen-fixing trees are planted and left to rest for one or more seasons to improve SQ in agricultural fields (Franzel, 1999). An example of fallowing is shown in Figure 1. Fallowing extends back to the ancient Romans, who depended on this method to improve crop yields (White, 1970). However, in contemporary times, as population sizes increase, fallow periods are reduced, and continuous cropping has become more frequent (Franzel, 1999). However, this does not mean that fallows are ineffective for agroforestry. In fact, the improved tree fallow is a more flexible approach than other practices, such as alley cropping, in which trees are grown simultaneously with crops (Franzel, 1999). This is because alley cropping is labor-intensive; hedges must be cut back repeatedly to avoid competition with crops. In clear contrast, trees in a fallow are less labor-intensive since they can be cut over a period of weeks before land preparation begins (Franzel, 1999). Understanding the economic viability of such methods is important for determining whether they are a suitable option for low-income farmers.

Figure 1. Maize cultivation in the Batéké Plateau, Republic of Congo, following a fallow year of Acacia auriculiformis. Source: Photograph by Dominique Louppe (2008).

5.2 The Economics of Improved Tree Fallowing

Because a segment of the agricultural field lies idle for a season or more, one would intuitively expect that a yield must be at least double to make up for the lost production during the fallow. However, improved fallowing yields require much less labor and thus less fiscal costs. Therefore, only a 21% increase following the fallow season is needed to break even (Franzel, 1999). Over a five-year period, a case in Zambia found that fallow plots used 11% less labor compared to unfertilized maize but harvested 83% more produce (Franzel, 1999). In some cases, returns to land were over 20 times higher on an improved fallow plot (Franzel, 1999). An economic analysis of improved fallows found that a two-year fallow yielded the most profitable results compared to a one- and three-year fallow (Franzel, 1999). Furthermore, the improved

fallow offers impressive returns but requires minimal cash inputs (Franzel, 1999). Research has shown that low-income farmers across multiple developing countries are more likely to adopt improved tree fallows versus inorganic fertilizers, likely because the fallows require little cash (Franzel, 1999). This is especially appealing to cash-strapped communities struggling with soil degradation. In this way, improved tree fallows are a possible people-first approach to SQ restoration that utilizes tree-planting effectively. While these economic benefits are compelling, some farmers have developed even more cost-effective adaptations of the fallow approach.

5.3 The Invasive Tree Fallow

Low-income farmers have developed innovative, opportunistic approaches to restore SQ to further reduce the cost of improved tree fallows. Some researchers argue that, because improved tree fallows may still be too expensive for low-income farmers in some cases, they have not been widely adopted (Tassin et al., 2012). To remedy this problem, low-income farmers have "developed a novel approach to agroforestry fallows by taking advantage of spontaneous invasions of woody leguminous tree species present in the vicinity of their fields" (Tassin et al., 2012). This approach is particularly effective because the characteristics of tree species in improved fallows are shared by many invasive plants (Richardson et al., 2003). Though these trees are labelled as invasive by environmentalists, this does not discount their usefulness to the world's poorest communities (Tassin et al., 2012). Further, taking advantage of the characteristics of invasive species is a cost-effective and pragmatic strategy for restoring SQ (Tassin et al., 2012). It has also been shown that, compared to other methods of fallowing, opportunistic invasive fallowing is more efficient at restoring SQ over a shorter period and more profitable, making it a more viable solution for low-income farmers wishing to improve SQ, as illustrated in Figure 2. Beyond reducing costs through invasive species, farmers have also discovered ways to enhance the economic and nutritional value of fallows.

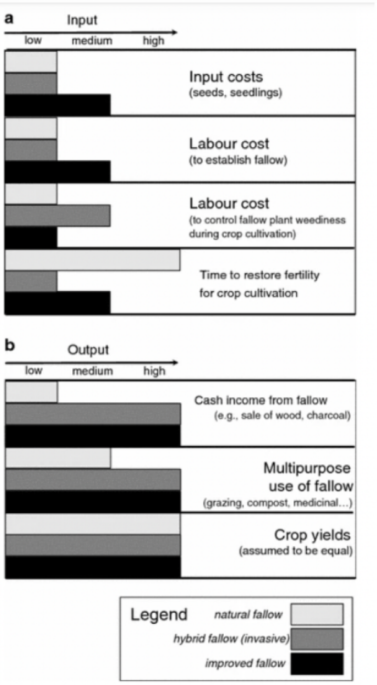

Figure 2. Hypothetical differences in input costs and outputs across natural, hybrid (invasive), and improved fallow systems influencing adoption decisions. Source: Reproduced from Tassin et al. (2012).

5.4 The Hybrid Fruit-Bearing Fallow

Through the use of fallows, farmers can increase the amount of economically valuable tree species without much labor or intense planting efforts. When farmers

leave valuable trees standing, such as fruit and palm species, and clear the other varieties, these economically valuable trees will drop seeds that can grow well in newly created fertile soil (Unruh, 1990). Over many fallow cycles, the area will accumulate more useful species without requiring the individual planting of each tree (Unruh, 1990). This method can replenish nutrients in the soil and improve the rate of soil recovery (Unruh, 1990). In addition, a fruit-bearing fallow can yield many benefits beyond improving SQ, such as helping alleviate labor and capital constraints, as well as providing additional income through the sale of fruits at market (Szott et al., 1991). In addition, fruit may help to alleviate some susceptibility to malnutrition by restoring nutrients to produce. In turn, this could help the world's poorest communities avoid falling into poverty traps due to malnutrition, as mentioned above. The benefits of fallowing go beyond just soil fertility and nutrition and include significant pest management advantages.

5.5 Fallows and Pest Reduction

Research conducted by the United States Department of Agriculture found that in California peach orchards, one year of fallowing increased tree growth by 50% (Trout et al., 2001). Further, yields increased by an average of 20% after three to five years. The research found that after three years of fallowing, it was as effective as methyl bromide fumigation without a fallow period for removing pests (Trout et al., 2001). These findings demonstrate that fallowing is an effective method for improving tree growth, producing yields, and eliminating pests. Pest reduction is just one of several non-soil benefits that motivate farmers to adopt improved fallows.

5.6 Additional Benefits of Fallows

Improved fallows provide additional benefits beyond soil and pest-reduction benefits. For example, farmers who planted improved tree fallows also received additional benefits, including honey, stakes, and fuelwood, which can be sold at market (Degrande, 2005). In some cases, these products were so beneficial that farmers adopted tree fallows in the first place because of these additional benefits, and not primarily because of improved soil fertility (Degrande, 2005). This further demonstrates how improved tree fallowing benefits people while simultaneously improving SQ and contributing, in part, to tree-planting efforts. However, like many nature-based solutions, fallows should not be treated as a cure-all. Despite the numerous advantages, it is important to acknowledge that fallows are not universally applicable or without limitations.

5.7 The Pitfalls of Fallows

Fallows may not be attainable for all low-income farmers. This is because fallow plots require moderate to high amounts of land availability, which may be unrealistic to leave idle compared to continuous cropping in certain contexts (Szott et al., 1991). Research has shown that in systems with abundant land, fallowing is more feasible than in land-scarce areas (Franzel, 1999). Further, as shown previously in this paper, longer fallow periods are more profitable, but these plots lock land up for a long time, which may not be profitable for some low-income farmers. In addition,

leaving segments of a field idle may contribute to food security risks, despite a 21% increase over a fallow field (Franzel, 1999). In this way, fallows might increase a community's income but not its food supply, which can be hazardous if they are self-sufficient (Franzel, 1999). This means that fallows can create short-term food insecurity. Furthermore, low-income communities that cannot afford to buy nitrogen-fixing trees for improved fallow may be forced to rely on invasive species, which could pose problems for weed suppression in the future. Lastly, the benefits of improved fallow may be overemphasized because the market value of these commodities is not uniform, which could be harmful if farmers rely on these by-products to support their livelihoods. These limitations demonstrate the importance of context-appropriate implementation.

Conclusion

This paper has examined the complex relationship among large-scale tree planting, SQ, and chronic poverty. It builds on previous unpublished findings that large-scale tree-planting yields mixed, context-dependent results regarding SQ. The evidence reviewed in this paper demonstrates that SQ and poverty can create feedback loops that trap the world's poorest communities into chronic poverty in multiple ways (Barrett and Bevis, 2015).

Given this relationship, the promotion of large-scale tree-planting as a global climate solution must be heavily scrutinized; if large-scale tree-planting does degrade SQ, which research has shown it does, these methods are no longer "solutions" but instead risk widening the poverty gap for the world's poorest communities. Therefore, a business-as-usual approach to large-scale tree-planting jeopardizes those who are dependent on soil to maintain their livelihoods. Further, this paper discusses how inorganic fertilizer is often inaccessible to the developing world, where the majority of soil degradation occurs (Kim and Bevis, 2019). Therefore, even though a solution to SQ may exist for these communities, it is often out of reach. In response to these challenges with both tree-planting and inorganic fertilization, this research has identified promising alternatives.

This paper then investigates the improved tree fallow, as well as hybrid and invasive fallowing methods. Based on research, the fallow seems like an effective, people-first alternative to improving SQ that works for the world's poorest communities. This is because these strategies require little cash, reduce labor efforts, and provide additional benefits that can be sold at market. These benefits help demonstrate the potential of fallows where other methods fail.

Importantly, the fallow approach is promising for poor farmers because it allows them to substitute resources they have (e.g., land and labor) in turn for cash, a scarce resource (Degrande, 2005). Fallowing is accessible for low-income farmers, as research has found chronically poor communities were able to successfully adopt improved fallows (Degrande, 2005). In clear contrast, inorganic fertilization efforts require cash investments upfront, which excludes chronically poor communities.

As the world continues to pursue large-scale tree-planting, policymakers must become increasingly cautious to prevent exposing the world's poorest communities to poverty traps caused by soil degradation. The improved, invasive, or hybrid tree fallow demonstrates a possibly effective approach that can improve SQ, alleviate the effects of poverty, and contribute, in part, to reforestation efforts. However, these methods must be implemented with much attention to local contexts, economic constraints, and farmer consent.

Moving forward, this paper recommends higher standards for large-scale tree planting to prevent inadvertently creating poverty traps for the world's poorest. In addition, educating more low-income farmers in the developing world about the benefits of tree-fallowing could be extremely beneficial; not only could more farmers improve the SQ in their fields, but they could also mitigate the effects of climate shocks, increase yields, and receive other non-soil-related benefits, which may bolster their income. Lastly, this paper calls for further research to understand the effects of soil carbon and sequestration in improved fallow plots, enabling a more effective examination of the climate-mitigation impact of improved fallows.

Statement of Generative AI Use

Generative AI (Claude) was used to assist with organisational structure and editing for clarity. All research, analysis, synthesis, and argumentation are entirely my own. Grammarly was used to spell-check work.

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Consilience: The Journal of Sustainable Development
Iss. 28 (2026)

CONSILIENCE
THE JOURNAL OF SUSTAINABLE DEVELOPMENT

The Role of the Mongolian Women's Farmers Association in Addressing Food Security and Health Crises in Post-Socialist Mongolia

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Abstract

Since the fall of the Soviet Union in December 1991, one of the most pressing challenges faced by post-socialist states has been widespread malnourishment and food insecurity. In response to these systemic issues affecting the daily lives of rural nomadic communities in Mongolia, the Mongolian Women's Farmers Association (MWFA) has aimed to equip farmers across the country with the agricultural knowledge and materials needed for sustainable self-sufficiency. In this paper, I argue that the Mongolian Women's Farmers Association is a vital response to the ongoing food and health crisis within Mongolia, focusing its efforts on food diversity, traditional farming tactics, economic instruction, and ecofeminism. Using ethnographic research, survey data, secondary scholarship, and historical records, this research paper is designed to combine elements of nomadic lifestyle with aspects of more modern agricultural technology to improve Mongolian food habits. The research finds that often in post-socialist countries, due to weak infrastructure, difficulties transitioning from state-controlled to market economies, and dependency on said markets, systemic food insecurity is much more prevalent. For a country like Mongolia, a large percentage of nomadic communities face dire health consequences due to their diet of mainly meats and dairy, and because of sporadic weather patterns, are losing their ability to mobilize to new regions. Many communities lack the knowledge needed to grow and maintain vegetable gardens, making the prospect of surviving in a climate change–affected world increasingly daunting. In addition, much of the farming responsibilities are culturally given to the women, making the MWFA's goals all the more relevant to the current socio-cultural norms of Mongolian society. This paper contributes to the ongoing debate over how food sovereignty movements can survive in post-socialist spaces and provides evidence of how Mongolia can decrease food insecurity nationwide.

Author's Note

My name is Griffin W. Sanford, I'm a rising junior at Vassar College,

Poughkeepsie, NY, 12604, and I'm currently double majoring in International Studies and Russian Studies. This paper was written as the final project for an anthropology course entitled "*Food and Indigeneity*," taught by food scholar Dr. Mark Chatarpal. The goal of this course was to highlight the work of indigenous scholars across the world (more specifically in the Global South). After much deliberation, I decided on the Mongolian Women Farmers Association. I believe their work is incredibly timely and holds immense potential for advancing sustainable development in Mongolia and other struggling states around the world. Additionally, as someone who grew up with a single mother, I found their focus on teaching single mothers self-sufficiency inspiring. Their approach embodies social empowerment rooted in community and compassion, in addition to agricultural resiliency.

Keywords: Food Sovereignty, Ecofeminism, Mongolia, Post-Socialist

Introduction

As the global community continues to struggle with combating widespread poverty, rampant undernourishment, and environmental degradation, the knowledge and ideas of indigenous communities, along with the need for more sustainable food systems, are becoming increasingly valuable within policy discussions. Mongolia, a country founded on its traditional pastoral legacy, serves as an insightful case study. Due to the country's post-socialist transition to a market economy in the early 1990s after the fall of the Soviet Union, centralized agricultural structures collapsed, leaving rural herding communities to feel the brunt of the rising poverty epidemic. Adding to this economic pressure, the ongoing health crisis perpetuated by unhealthy diets, parallel with the loss of land and livestock due to climate change, has severely impacted the way of life for many herding communities. The role of women in food production has also emerged as a central concept in the establishment of sustainable food structures, forging a path towards the creation of more tight-knit and resilient rural communities. With this information in mind, drawing on government documents, ethnographies, secondary sources, surveys, and case studies, this paper argues that the Mongolian Women Farmers Association (MWFA) plays a crucial role in confronting the failures of Mongolia's food systems. By combining sustainable farming practices, indigenous knowledge, economic education, and women's empowerment, the organization offers a locally rooted, gender-conscious response to food insecurity, public health crises, and the detrimental effects of climate change.

Theoretical Framing

This paper is heavily influenced by existing food sovereignty literature, which focuses directly on uplifting local communities to control their food systems, as well as the concept of ecofeminism, which exemplifies the role of women within all aspects of food production. Popularized by the international movement known as La Via Campesina, food sovereignty was initially brought into global discussions of food policy during the 1996 World Summit in Rome. After years of debate, the term was finally established within the Declaration of Nyéléni in 2007 as "the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agricultural systems" (Nyéléni Forum for Food Sovereignty, 2007). Through this framework, groups like La Via Campesina hoped to amplify the needs of indigenous people within governmental food policy, as well as protect and conserve traditional agricultural and cosmological practices. Adding on to this idea, during the late 2000s, Hannah Wittman's *Food Sovereignty: Reconnecting Food, Nature & Community* became one of the more influential texts in the food sovereignty space, translating the movement into a more policy-oriented academic discussion. Wittman presents her idea of food sovereignty as an agrarian citizenship, where individuals are entitled to influence the laws and procedures governing production, food, and land (Wittman, Desmarais, & Wiebe, 2010). Using this lens, she critiques neoliberal agricultural reforms such as the privatization of land and resources, removal of trade barriers and subsidies, and the promotion of monocultures that seemingly disadvantage small-scale farmers in the Global South. She also takes a stance against the idea of a "technocratic approach" to agricultural

development, where institutions such as the IMF and World Bank actively sideline indigenous and cultural agricultural knowledge.

Building on Wittman's findings, Food sovereignty has also been analyzed through the corporate commodification of food. Raj Patel outlines how the consolidation of power within agribusiness undermines traditional food practices and erodes cultural foodways (Patel, 2007). Through the privatization of land, water, and even seeds, Patel shows how farmers are losing their autonomy within the industry, and argues that the international system needs to restructure its food systems to invite better democratic and sustainable reforms. While Patel focuses on more large-scale structural power dynamics, scholars Oane Visser & Natalia Mamonova outline a more localized and subtle approach. In post-socialist countries with fewer opportunities to challenge government policies, Visser and Mamonova describe a phenomenon they refer to as "quiet food sovereignty" (Visser, Mamonova, Spoor, & Nikulin, 2017). Using Russia as a case study, they show that while outwardly vocal food sovereignty movements are virtually non-existent, food sovereignty does exist through the substantial utilization of dachas and secondary plots for smallholder production by rural and urban households. Using this frame of reference, the authors explain that although less mobile, quiet food sovereignty is not apolitical, and shows that the social dimension of "everyday resistance" is just as important for the development of food sovereignty across all political systems.

In addition to these arguments, this paper is also focused on the intersection of both food sovereignty and ecofeminism, connecting how food systems interact with the empowerment of women in agricultural spaces. World-renowned scholar Vandana Shiva argues that women, specifically in Indigenous and Global South contexts, play a crucial role in the sustainment of biodiversity and traditional agricultural knowledge (Shiva, 1993). Taking Patel's findings further, Shiva describes how Western industrial structures and capitalism exploit women's labor and knowledge in the agriculture sector, leading to the promotion of monocultures and corporate control over seed production. Expanding upon this, Dianne Rocheleau & Barbara Thomas-Slayter argue that landscapes are gendered, outlining how they are split between men and women based on differing social dynamics and labor responsibilities (Rocheleau & Thomas-Slayter, 1996). They also contend that women's work managing forests, water, and food is often undervalued, creating a stark contrast between how men's and women's labor is perceived societally. Furthermore, Bina Agarwal's findings while studying collectives of group farming in South Asia showed the importance of land ownership for the economic and social empowerment of women's rights (Agarwal, 1994). Through her research, she highlights the essential nature of collective action, as women who work in groups have an easier time mobilizing, gaining a voice, and earning credibility. When utilized together, these frameworks of ecofeminism and food sovereignty offer a critical lens through which this paper analyzes the Mongolian Women Farmers Association, showing how gendered, grassroots agricultural practices can promote sustainable food systems in post-socialist environments, combat neoliberal development, and restore local autonomy.

Mongolia's Post-Socialist Transition and Its Effects on Agriculture

To begin, it is crucial to acknowledge the historical background of Mongolia's food systems, and where many of these issues originated. During the collective period, Mongolia's agricultural systems were split into two frameworks, where state farms focused on agricultural experiments/crossbreeding, and institutions known as *negdels* focused on pastoralism (Visser & Schoenmaker, 2011). The *negdels* were hierarchically organized, and specialized in differing livestock types. Mongolia's central planning apparatus set quotas for each member, as well as gave them a set of tasks to fulfill, however, in practice, most herders had a lot of flexibility and had significant influence in terms of pastoral management decisions. Along with being a hub for agricultural employment and production, the *negdels* were also known as "total institutions", equipped with well-arranged social facilities such as production and supply systems, schools, veterinary centers, marketplaces, and water stations (Visser & Schoenmaker, 2011). At its peak, a *negdel* could have over 1,000 members, half of whom engaged in herding (Visser & Schoenmaker, 2011). Not only were these services critical for the livelihoods of thousands of Mongolian farmers and herders, but they also allowed people to earn stable incomes, gain education, and have access to developed healthcare facilities.

Moving into the 1990s with the fall of the Soviet Union, and the loss of significant funds towards the *negdels*, Mongolia's economy was thrust into immediate economic decline. The country's introduction of "shock therapy" (transition from centralized to market economy) into their economy dissolved the well-funded state-owned farms, led to significant job losses, and forced a majority of the population back into the herding workforce (Sankey et al., 2018). To sustain themselves, this change caused farmers and herders to individually privatize. This privatization of livestock resulted in the exponential growth of the share of individually owned livestock, which increased from 23% in 1990 to 80% in 1993 (Visser & Schoenmaker, 2011, p. 30). This rapid decollectivization led to the disappearance of essential collective services such as mechanized fodder production, transportation materials, and marketing provided by the *negdel*, which forced rural households to survive largely on a subsistence basis. Scholars Visser & Schoenmaker in their comparison study of Mongolia and Russia's agricultural post-socialist transformation contend that one of the main reasons for Mongolia's rapid demise in the farming sector is because of the population's dependence on the *negdels* social systems (Visser & Schoenmaker, 2011). On a more environmental note, as argued by Temuulen Sankey, following the collapse of its socialist regime, Mongolia experienced substantial changes in its cropland extent and distribution methods that drastically affected the rural herding population. In their study, they found that due to privatization, there has been an estimated 38% decline in cropland across the major crop regions of Mongolia between 1990 and 2014, leading to land degradation and causing the country to be more reliant on imports from countries like China and Russia (Sankey et al., 2018). Together, these issues compiled together have caused herders to become incredibly vulnerable to anything from market shifts to dangerous weather patterns, ultimately entrenching financial instability and widening rural inequality.

Traditional Herding Lifestyle and Its Strain in the Modern Era

For rural Mongolians, the tenacious challenges brought forth by the country's post-socialist transition are often exacerbated by their unique nomadic herding lifestyles. In traditional Mongolian nomadic culture, their livelihood is often centered on extensive multispecies animal husbandry, where most families herd both large livestock (horses, camels, and cattle) and small livestock (sheep and goats) (Janzen, 2005). This type of practice has been handed down for many generations and is said to maintain the delicate and highly anthropized steppe ecosystems by distributing grazing stress among species (Peter et al., 2024). The pastoral space itself is separated into concentric circles, with the human body at the center, then the yurt (or rarely other types of more modern shelter), the camp, and finally the pastoral lands that are separated for each species' ecological needs (Marchina, 2021). As described in Indigenous scholar Hotta Ayumi's ethnography *Stories of the Enkhbat Family*, the yurt or *ger* holds deep cosmological significance. When nomads marry, they leave their parents' home and establish a *ger* of their own (Hotta, 2021).

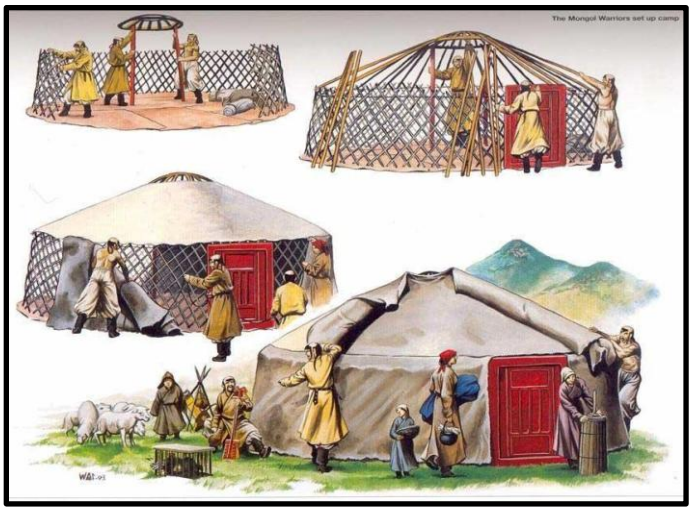

Figure 1. Discover Mongolia Travel, "Ger, Mongolian Traditional Dwelling," accessed May 3, 2025, https://www.discovermongolia.mn/about-mongolia/culture-art-history/ger-mongolian-traditional-dwelling.

Additionally, nomads are inherently movement-oriented, and seasonal migrations are perfectly timed to maximize pasture carrying capacity and ensure the livestock survives through rough cold winters and dry springs. One of the most important aspects of Mongolian nomadic culture is centered around the appropriation and management of natural conditions, where communities are often faced with tackling differing climatic levels and irregular weather patterns (Legrand, 2000). In terms of cultural foods, the dietary traditions among herding families are primarily based on meat or dairy-based dishes. Mongolians view meat as the only food that can truly 'nourish' them, with most families maintaining a continuous meat broth simmering over the fire. Mongolians have a strong emphasis on preserving hospitality rituals during all meals, only eating inside the *ger*, facing the soles of their feet towards

the door to rid out negative energy, and ensuring they are always under the protection of the fire spirit (Williot & Bianquis, 2019).

Although Mongolian nomads have been able to sustain their way of life for thousands of years, following the elimination of the *negdels,* herders were incentivized to maximize their herd sizes, causing the livestock population to boom from 22 million in 1940 to over 40 million today (Lkhagvadorj et al., 2013). In an examination of the socio-economic challenges to herder households in Mongolia, Michler & Kaczensky found that there is an average of 653 livestock per household, with many herders describing their desire for more to guarantee a better financial standing (Michler et al., 2024). This rapid increase has caused significant grassland degradation and economic decline, ruining pasture quality and inviting pernicious forest grazing. In a similar vein, the shifts in agricultural policy and elimination of programs that worked to market herders' meat and dairy products have left many economically exposed. High transportation costs make it difficult for herders to sell livestock products in urban markets, leaving them heavily dependent on unstable cashmere sales, which currently make up around 70 percent of their herding income (Michler et al., 2024).

Given these blatant economic disadvantages, there has been a recent societal shift among younger generations, who are increasingly moving away from sedentary lifestyles and toward more urbanized spaces. Although existing literature such as Peter & Niess (Peter et al., 2024) and Gardelle & Zhao (Gardelle & Zhao, 2019) contend that intergenerational traditional nomadic knowledge in Mongolia within younger generations is relatively strong, Katarzyna Golik argues that there has been a significant trend of migration away from rural pastoral spaces among the newer generations (Golik, 2021). Through interviews from 2007 and 2019 respectively, she discovered that a majority of the younger generation believed traditional pastoral life was too difficult, hoping for better living conditions, education, and healthcare within the major cities. She also expressed how Indigenous knowledge is potentially being lost through this urbanization process, giving the example of a 10-year-old girl living in Ulaanbaatar whose parents rejected the need for her to learn their ancestral language, citing it as "useless" (Golik, 2021, p. 55). This potential loss of indigeneity through urban migration signals a societal shift in the way Mongolian nomadic lives operate, posing a serious threat to the sustainable ecosystems and traditional food knowledge that has existed within Mongolian society for generations. With these issues of cultural erosion, economic volatility, and environmental destruction seemingly getting worse every year, the work of grassroots organizations such as the Mongolian Women Farmers Association becomes increasingly crucial for the conservation of pastoral culture legacies.

How MWFA Fills The Gap

As outlined by the theoretical frameworks of both food sovereignty and ecofeminism, smaller-scale community-led efforts focused on women's labor and sustainable food practices are crucial for addressing ongoing ecological and economic crises across the world. In practice, the Mongolian Women Farmers Association exemplifies these concepts, offering a unique solution that empowers rural communities to practice greater self-sufficiency and gain more control over the

domestic agriculture industry. Founded in 1999 by Mrs. Byatshandaa Jargal, this non-profit, non-partisan, non-denominational organization was created to directly support low-income families, and more specifically, single mothers, to grow and sell their own organic and sustainably produced vegetables (Mongolian Women Farmers Association, n.d.). Knowing the ongoing health and food insecurity crises in Mongolia, the organization has focused on teaching the cultivation of various vegetable seeds, explaining the process of constructing greenhouses, breeding and planting different types of native trees, and restoring soil. Participants receive seed packets in the mail and sometimes are provided with a plot of land on a community farm (Nelson, 2009). Adding on to this training, the program also shows families how to use their crop cultivation to gain alternate forms of income. This has enabled many single mothers to afford their children's education while fostering a tight-knit community that upholds deeply rooted cultural values (Mongolian Women Farmers Association, n.d.). In addition to their in-person training, the MFWA has also utilized YouTube through their channel @MNwomenfarmers to reach a wider audience. Their training ranges from 2-10 minutes and have amassed an average of 22,000 views across 10 different videos (MNwomenfarmers, 2010). Since its establishment, the organization has supported over 5,300 households across Mongolia, illustrating how state-level deficiencies in food security and women's empowerment can be addressed at the local level. On top of that, Byatshandaa herself has written many textbooks in Mongolian bridging vegetable farming with traditional animal husbandry, promoting eco-friendly solutions that work within the bounds of nomadic and pastoral lifestyles (Nelson, 2009).

The MWFA can be described as a perfect example of quiet food sovereignty, as while the program does not make overtly political statements, it does radically reimagine how food is produced and controlled. By focusing on sustainable farming methods and the enhancement of community-driven projects, the organization "quietly" challenges the existing agricultural sector's policies, especially those considerably influenced by post-socialist reforms. Through this dynamic, the organization can uplift marginalized groups by providing them with the tools to engage in their own food self-sufficiency, strengthening local economies in the long term. In one case, a local woman who was left disabled in a fatal car crash began growing vegetables based on MWFA's guidance. It has since become her main source of income and food. She is now even able to combine traditional meat soup with the variety of vegetables she grows for her daughter and husband (Strzyżyńska, 2024). Furthermore, the MWFA's emphasis on providing educational tools to grow your own food and women's livelihoods represents an interesting intersection of food sovereignty and ecofeminism. As discussed, a woman's role as the primary caretaker is often downplayed, and the MWFA is fighting directly against this narrative on both societal and economic levels. In an interview with *The Guardian*, Byatshandaa explained why the program was directed toward women stating, "I thought that by training women how to grow vegetable gardens, I could help families by giving the mums something productive to do while also providing the household with a source of food and income" (Strzyżyńska, 2024). Altogether, the organization offers valuable lessons for similar rural and disadvantaged communities around the world, integrating gender-focused empowerment, local knowledge, and many of the core principles outlined within food sovereignty.

Role of Women in Food Production

When considering the broader context of women's contributions to Mongolia's agricultural and pastoral industries, the importance of the MWFA becomes even more clear. Historically, women in Mongolia are well known for their strength and influential wisdom. Being seen as equal leaders to men, Mongol Queens are celebrated for their role in governing over large areas, serving as judges, commanding in battle, and taking part in open athletic events (Ulambayar & Ferández-Giménez, 2013). Within pastoral society, women take on the role of essential caretakers, ensuring their families are well-fed. Inside the *ger*, women play a crucial role in the production and processing portion of their herds, with their duties including: herding small livestock, milking, transforming raw or processed foods into meals, and shearing/cutting the animal's coats (Cooper & Gelezhamtsin, 1999). Overall, with all these jobs combined, women make up around 42% of the agricultural sector (Ulambayar & Ferández-Giménez, 2013).

While this labor is seemingly respected on paper, these attitudes are not always reflected throughout herding society. Through a study that interviewed Mongolian herding women and their relationship to gender dynamics within pastoral landscapes, Cooper & Gelezhamtsin uncovered that due to the domestic nature of their responsibilities, women's labor is often overlooked (Cooper & Gelezhamtsin, 1999). Interestingly, they even discovered that because the daily labor profiles for women are divided between domestic and productive tasks, women often spend more hours working than men, shifting household burdens even more onto women. This devaluation continues into the economic sector, as in the post-socialist era, women are often classified as "unpaid family workers" in official governmental statistics (Benwell, 2006). This not only overlooks the crucial role women play in both family and agricultural life but also creates conditions in which female-led households face significantly greater financial burdens. Within the country, female-led households are usually constituted in poverty-stricken areas and are short of both labor and livestock (Rossabi & Rossabi, 2006). In an analysis of 140 pastoral communities across Mongolia, Mongolian researcher Tungalag Ulambayar noted that female-led households have significantly fewer durable assets compared to male-led households, including items ranging from trucks, cell phones, and other technology. She also noticed that women are marginally less likely to engage in collective action, losing out on the ability to share knowledge with older and wiser female heads (Ulambayar & Ferández-Giménez, 2013). In light of these mounting issues, the Mongolian Women Farmers Association's initiatives are becoming more and more important for guaranteeing food security in rural areas, preserving pastoral culture, and uplifting women's involvement in food production.

Food Insecurity and Health Crises in Rural Mongolia

These systemic challenges facing women in food production are inseparable from Mongolia's more comprehensive struggle with food insecurity and malnutrition, particularly in impoverished rural areas. As a result of the post-socialist agricultural and economic transition including widespread unemployment, weak financial and governmental institutions, and land degradation from overgrazing, Mongolia has faced

persistently high poverty levels. The percentage of impoverished people has been stuck at around an average of 27% for the past decade, with an unemployment percentage of 5.2% in 2022 (Asian Development Bank, 2024). Adding on to this, the poverty level within rural areas specifically is around 35% (Tserennadmid & Sugar, 2016), with another 50% of the entire population not able to afford a healthy diet (UNICEF, 2021). In a study testing Mongolian consumption habits conducted by Mongolian scholars Tserennadmid & Sugar, it was found that there is a large and statistically significant difference in nutrient consumption between poor and non-poor people within the region, with poor households below the benchmark level for all nutrients examined except animal fat . The study also found that undernourishment levels were deeply tied to both poverty and location, finding that 32.49% of poor individuals were undernourished compared to only 7.33% of non-poor individuals (Tserennadmid & Sugar, 2016, p. 66).

In terms of rural dietary intake, while the main crops grown within Mongolia are potatoes, cabbage, and wheat, most herding communities survive mostly on meat and dairy products. Due to a lack of knowledge when it comes to growing vegetables, and the constant cycle of movement because of seasonal differences, many Mongolians lack the essential nutrients needed from vegetables to stay healthy (UNICEF, 2021). In a study by Mongolian scholars Kadirbyek Dagys and Bakyei Agipar focused on how to maximize food value in chains in Mongolia, it was discovered that due to poorly diversified diets, Mongolians are at much higher risks of micronutrient deficiencies and dietary-related non-communicable diseases. These dietary deficiencies have been directly attributed to the country's high rate of obesity (29% of children and 63% of adults), high blood pressure levels (27.5% of adults), high cholesterol levels (61.9% of adults), and exceptionally high levels of anemia among younger children (27%) (Dagys et al., 2023). The study also highlights the extreme impacts climate-related events have had on Mongolian diets, as unpredictable seasonal patterns often increase the likelihood of livestock mortality and deterioration of soil fertility for crop growth. Most notably, the recent increase in frequency and intensity of extreme weather events during the winter months (*dzuds*) has played a significant role in the death of millions of cattle, meaning less to eat in general (Dagys et al., 2023).

Even further, Mongolia ranks first among all countries in the proportion of cardiovascular disease (CVD) deaths linked to dietary imbalances, largely due to the population's extremely high consumption of red meat, refined grains, and whole-fat dairy products (UNICEF, 2021). While there have been efforts to counteract these glaring public health crises in the form of food stamps and the establishment of a National Food Security Program in 2009, due to poor policy cooperation, low efficacy in implementation, and governmental structures still underdeveloped from socialist times, there has been little improvement in the betterment of rural Mongolian's diets and livelihoods (Tserennadmid & Sugar, 2016). As a result, programs such as the Mongolian Women Farmers Association have become crucial in managing these dietary imbalances, allowing impoverished people more access to nutritious and environmentally sound foods.

Conclusion

In the contemporary era, Mongolia's post-socialist transition has created a complex historical legacy of mass nutritional deficiency, rising poverty, ecological degradation, and the disintegration of traditional pastoral culture. As rural communities continue to be bombarded with the mourning pressures of extreme weather events, economic vulnerability, and rapid urbanization, governmental and public services have proven insufficient in addressing the intertwined crises of health, food, and gendered labor. Through this lens, the Mongolian Women Farmers Association rises as an important figure in combating these systemic dilemmas, promoting sustainable agricultural practices, bettering dietary habits, and teaching others how to attain economic independence. Informed through the ideas of food sovereignty and ecofeminism, the MWFA shows how gender-responsive, community-led solutions may successfully combat social inequalities and exploitative production systems. By encouraging rural women to cultivate their own crops, share traditional and educational farming knowledge, and establish stronger community resilience, MWFA offers a model of food sovereignty that is intertwined with ecological and cultural respect. As this paper has discussed, the gaps the MWFA fills within Mongolia's existing food structures serve as a powerful force towards the restoration of land-based food systems, specifically highlighting the importance of women's labor. The work of community-based groups like the MWFA is essential to creating a more equitable and sustainable future as Mongolia continues to negotiate a quickly shifting social and environmental terrain.

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Consilience: The Journal of Sustainable Development
Iss. 28 (2026)

CONSILIENCE
THE JOURNAL OF SUSTAINABLE DEVELOPMENT

Debt-For-Nature Swaps: An Analysis of a Climate-Financing Tool in Latin America

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Abstract

While the concept of protecting the natural environment is often popular, sourcing the massive funding required to reach global goals is a much more contentious topic. The purpose of debt-for-nature swaps is to supply part of this shortfall by tapping into government funds that are locked in sovereign debt obligations. Since these swaps began in 1987, they have been particularly popular in Latin America, a region that is rich in biodiversity and owes significant debt. While the swaps were popular at the end of the 20th century and the beginning of the 21st, they were criticized for being too small and fell out of favor in the 2010s. In the past four years, the swaps have reemerged, leading this paper to ask: what does the reemergence of debt-for-nature swaps signal for the future use of this financial instrument in Latin America; and furthermore, what are the opportunities and challenges for the future use of these swaps in the region? This paper argues that the recent swaps are uniquely characterized by credit enhancement, allowing them to be a degree of magnitude larger than past swaps; the large sum of funds and the political appeal of these swaps make them promising tools for funding conservation efforts.

Author's Note

My research grew from a desire to connect my studies in International Affairs and Finance and explore how financial systems can be used for sustainable purposes. I was additionally driven by a personal connection to Latin American and a passion for the environment. Debt-for-nature swaps not only addressed each of these issues, but I soon realized it was an especially timely topic due to recent innovations in the field. This research paper was completed as my senior thesis for the University Honors Program at the George Washington University (Washington DC, 20052). My sincere gratitude goes to Dr. Cynthia McClintock who advised my research.

Keywords: Sustainable Finance, Environmental Finance, Debt-for-Nature Swaps, Latin America, Credit Enhanced Swaps, Developmental Economics

Introduction

On November 24th, 2024, the 29th UN Climate Change Conference concluded. The conference, held in Baku Azerbaijan, included a series of hopeful, yet likely insufficient, initiatives to combat environmental degradation and global warming. The Executive Secretary of UN Climate Change, Simon Stiell, remarked, "[W]e leave Baku with a mountain of work to do. … So this is no time for victory laps, we need to set our sights and redouble our efforts on the road to Belem" (COP29 UN Climate Conference, 2024). The challenge that was central in Baku – and to climate change in general – is how to fund the transition to cleaner energy, conservation, and sustainability.

The purpose of debt-for-nature swaps is to supply part of this shortfall by tapping into government funds that are locked in sovereign debt obligations. Since these swaps began in 1987, they have been particularly popular in Latin America, a region that is rich in biodiversity and owes significant debt. While the swaps were popular at the end of the 20th century and the beginning of the 21st, they were criticized for being too small and fell out of favor in the 2010s. In the past four years, the swaps have reemerged, leading this paper to ask: what does the reemergence of debt-for-nature swaps signal for the future use of this financial instrument in Latin America; and furthermore, what are the opportunities and challenges for the future use of these swaps in the region? This paper argues that the recent swaps are uniquely characterized by credit enhancement, allowing them to be a degree of magnitude larger than past swaps; the large sum of funds and the political appeal of these swaps make them promising tools for funding conservation efforts.

This paper is divided into three sections that allow it to summarize previous research of debt-for-nature swaps and add to the conversation on the future of the swaps. First, it provides an overview of the history of debt-for-nature swaps, while highlighting their various forms and their relevance to Latin America. Second, this paper will explain how the new, credit-enhanced swaps work, while summarizing the six swaps in the most recent wave. In particular, the new credit-enhanced swaps are enabled by several factors: the focus on debt owed to private, rather than public, institutions, the use of insurance to raise the credit rating of the renegotiated debt, and the focus on large, connected swaths of debt. Third, this paper will demonstrate that the two most important benefits that make swaps so valuable going forward are the large funds that they can contribute and their appeal across the political spectrum. However, the challenges of debt-for-nature swaps must also be considered, particularly the claims of poor transparency, greenwashing, and institutional challenges.

It is important to note that two key decisions were made in the process of completing this research which affect its overall scope. The first is that conservation is seen as the primary goal of debt-for-nature swaps, rather than debt cancellation. While debt savings are an important variable of the swaps and are helpful for bringing Latin American countries to the negotiating table, the primary reason that these swaps are ultimately carried out is to generate conservation funds. For that reason, this paper focuses on the statistics of conservation funds generated and not debt savings when comparing swaps. Additionally, this paper measures success by the amount of funds

that make it into a country and not by the outcome of using those funds. While the efficient allocation of money for conservation projects is certainly important, each project is different and it is difficult to construct a measure, such as number of acres zoned off or number of species protected, that can be applied evenly across swaps.

The history of debt-for-nature swaps globally and in Latin America and the Caribbean

Origin of the debt-for-nature swaps

Understanding the history of debt-for-nature swaps is critical to understanding the renewed interest in swaps and how they can benefit sustainable finance. Debt-for-nature swaps were born amid a context of shifting environmentalism in the late 20th century (Macekura, 2016). In the 1970s, alongside changes in culture and politics across the world, environmentalism saw its own transformation. Ordinary citizens grew a heightened awareness of environmental concerns as conservation organizations grew in wealth and influence. Global environmental NGOs now had a seat at the table for powerful conversations about policy. This conversation manifested in greater environmental regulation and political backing for environmental goals. However, the conversation did not stay focused solely on policy for long and in the 1980s, the prevailing thought amongst environmentalists began to shift towards market mechanisms to further their environmental objectives (Macekura, 2016). Interest in solving issues of climate destruction and biodiversity preservation was still strong, but now many changemakers sought to solve these problems alongside—and not apart from – the prevailing free market model.

Amidst this changing philosophy was the debt crisis of the 1980s. This set the stage for the first debt-for-nature swap. In a New York Times opinion article titled "Aid Debtor Nation's Ecology," Thomas Lovejoy, the vice president for science at the U.S. branch of the World Wildlife Fund, first suggested that the problem of debt in developing nations and the risk of ecological destruction can be solved in parallel (Lovejoy, 1984). Lovejoy highlighted the fact that high levels of debt caused Costa Rica and Brazil to limit the resources that they designated for ecological programs, and, in regions like Latin America, can prompt the destruction of environmentally important lands for rapid export production. Debt-for-nature swaps could ameliorate these financial challenges while also infusing new funds and energy into environmental efforts (Lovejoy, 1984).

The first of debt-for-nature swap occurred between Conservation International and Bolivia. This swap involved $650,000 that Bolivia held in a Swiss bank, which Conservation International bought ("Q&A: Can debt-for-nature 'swaps' help", 2024). In return, Bolivia committed to protect almost four million of the Amazon Basin and invest $250,000 in conservation management ("Q&A: Can debt-for-nature 'swaps' help", 2024).

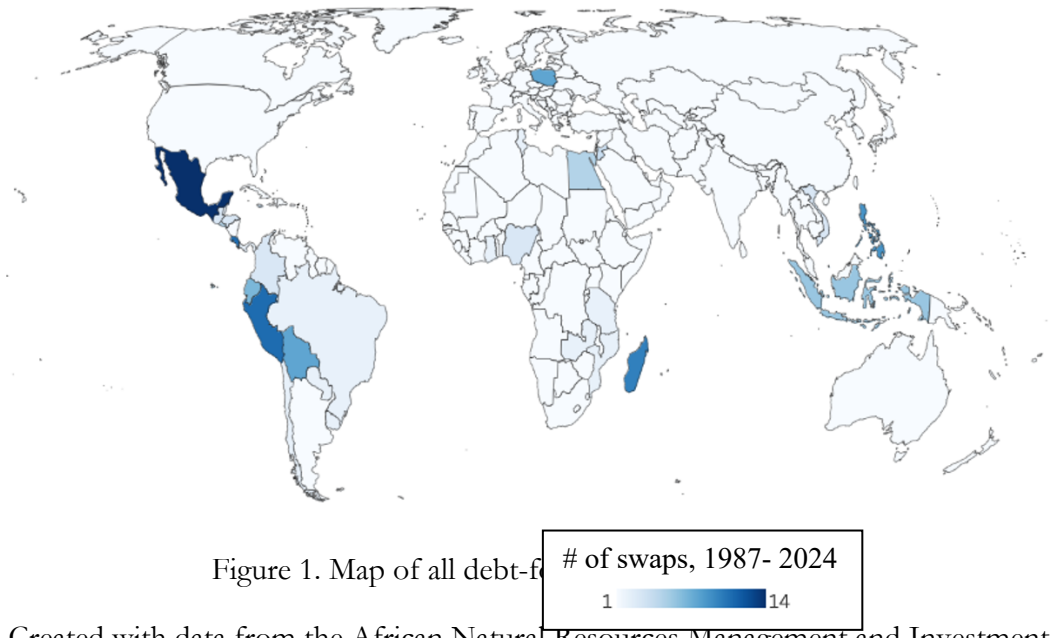

Figure 1. Map of all debt-f

Created with data from the African Natural Resources Management and Investment Centre, "Debt for Nature Swaps," 69-73. *Map created using Flourish.*

Since this first swap in 1987, more than 140 have occurred worldwide (Whiting, 2024). As the map shows, debt-for-nature swaps have been popular throughout the world, from the Americas to Africa, Southeast Asia, and even parts of Eastern Europe and the Middle East. However, the greatest concentration is found in Latin America, where 85 swaps have occurred since their start ("Q&A: Can debt-for-nature 'swaps' help", 2024).

Latin America is, in many ways, the ideal region for debt-for-nature swaps. The region has a wealth of biodiversity that is a treasure for the region and the world. The UNEP estimates that around 60% of "global terrestrial life" is within the region ("The State of Biodiversity," 2016). And there are likely even more species in Latin America than we know about, extending to far more than just the widely recognized Amazon rainforest, which already is home to 10% of global biodiversity (Carey-Webb, 2020). In addition to aiding biodiversity, the region is also important in combatting climate change. The Amazon, for instance, is a vital carbon sink (Gatti, 2021).

Latin America also has struggled through various economic challenges. Over the last decade, the region's debt-to-GDP ratio has crept up due to falling commodity prices. It peaked sharply during the COVID-19 crisis, when countries borrowed heavily to support healthcare and income support as economic activity slowed. The average domestic fiscal support package in Latin American and Caribbean countries was 8.5% of GDP (Powell, 2023). These factors all contributed to total external in Latin America and the Caribbean peaking at 55.89% of GDP in 2020. Some improvements have been seen; external debt in 2024 has lowered to 40% ("World Economic Outlook Database," 2024).

The remainder of this paper will focus on Latin America, although many of the themes—such as the evolution of the swaps, and many of the challenges and promises of new swaps—can have global implications.

The evolution of debt-for-nature swaps

As Latin America went through economic swings in the past 50 years, debt-for-nature swaps also evolved. The phases of innovations can be broadly categorized into three phases: first, private swaps financed by NGOs; second, public swaps between two countries; and third, credit-enhance swaps. The phases of evolution are not exclusive and there is often overlap in when they were used.

The first debt-for-nature swaps, including the Bolivia swap, were financed by NGOs. Other parties were still involved, such as the bank to which the indebted country owed money (Jha, 2001). Since the country's debt would be trading at a heavy discount due to concerns about their inability to pay, the NGO could buy the discounted debt at a relatively cheap price. This enabled the NGO to negotiate with the indebted country so that a sum between the trading price and face value of the debt could be channeled towards conservation efforts or the NGO could require that various conservation projects be undertaken. This meant that an environmental organization could essentially multiply the impact of their money by first buying up debt. As a very simplified illustration, suppose an NGO wants to invest $100 million in a country for conservation efforts, and debt from county A is trading at 25 cents on the dollar. The NGO could use the $100 million to buy back $400 million face value worth of debt. It is unlikely that the country has the funds to invest the full $400 million, but, for instance, the NGO could require investment of $200 million into conservation efforts to forgive the loan (Reiner, 1992).

The second generation of swaps are bilateral public swaps that happen when a country forgives part, or all, of another country's debt in return for conservation commitments or investments. While the first public swap happened in 1988, just a year after the Bolivia swap, they did not truly become the dominant swap until the early 1990s ("Q&A: Can debt-for-nature 'swaps' help", 2024). An analysis of data from Carbon Brief's 2024 article "Q&A: Can debt-for-nature 'swaps' help tackle biodiversity loss and climate change?" shows that from 1987 to 1991, only 27% of swaps in Latin American and the Caribbean were bilateral public swaps. But, from 1992 to 2010, these public swaps accounted for 78% of swaps in the region. The benefit of these swaps was that they were for much larger amounts of debt than the first wave of private swaps. This was aided by the fact that in the early 1990s, the Enterprise for the Americas Initiative pushed forward billions of dollars of swaps for Latin American and Caribbean countries. In 1993, for instance, a half dozen Latin American countries received a total of $90 million reduced in face value of their debt. In addition to the political willpower behind the public debt swaps, there is also simply more debt to work with, as countries owed more to other countries than private banks (Jha, 2001).

Between 2010 and 2021 there were no debt-for-nature swaps in Latin America, possibly due to the leveling of debt in the region. But, the post-COVID wave has seen a resurgence and has included six debt swaps up to Fall of 2024. The dominant form

of these new swaps appears to be a credit-enhanced swap. While "Credit-enhanced" is not yet a commonly published term for swaps, a November 2024 interview with Zanetti Balparda Maria Pia of the Inter-American Development Bank suggests it is becoming more common within the world of debt-for-nature swaps. The Nature Conservancy (TNC) is one of the largest NGOs involved in this new type of swap, with swaps in Belize and Barbados. This new type of swap holds promise for significantly increasing the size of debt that can be purchased and ultimately the amount of funds that can go towards conservation.

Historical criticisms of debt-for-nature swaps

Throughout their history, debt-for-nature swaps have attracted several criticisms. The main arguments are that the swaps are not large enough, that negotiators struggle to strike the right balance with local stakeholders, and that swaps could introduce inflation.

The most prevalent criticism of debt-for-nature swaps was that they were not large enough to address either a country's large debt or its environmental needs. A report on the first 25 debt-for-nature swaps globally showed that the total percentage of debt swapped to total debt was only 0.0472% (Kushner, 1991). And, while the swaps did more to address environmental needs, they got nowhere close to the estimated minimum $470 billion that needs to be invested in Latin America and the Caribbean to reach the Paris Agreement goals (Powell, 2023). Although it would be illogical to argue that debt-for-nature swaps are bad simply because they are not large enough, it could be argued that they detract attention from other strategies that could do more to help our environmental crisis.

Next, some debt-for-nature swaps struggled to properly integrate local stakeholders, including both the local organizations that would administer the projects and the public, whose implicit approval is crucial for successful environmental work. It is often difficult to balance the desire to give the country as much autonomy as possible while also ensuring the managers of the funds and the environmental projects have the necessary expertise. Simply giving local organizations the money and then taking a step back was often not favorable. However, when international organizations took greater control of the funds and their management, they could add to the perception that the indebted country was selling away their land or otherwise giving up part of their sovereignty ("Q&A: Can debt-for-nature 'swaps' help", 2024).

The third, and arguably the most theoretical, argument against debt-for-nature swaps is that they could cause inflation (Kushner, 1991). The argument proposes that if a country, such as a small island nation, were to receive hundreds of millions of dollars of money infused into the economy, then that country would experience serious inflation. Practically speaking, however, debt-for-nature swaps in the past were not large enough for this to be a real concern. However, this concern may need to be re-visited in the future.

The new generation of debt-for-nature swaps

The recent debt-for-nature swaps are a distinctly new generation of swaps and have reemerged on a significantly larger scale. They leave observers wondering: can this generation of swaps solve the challenges of the past while addressing the new environmental and financial circumstances of today? To address these questions, we will first discuss how these swaps are different from the past, summarize the six most recent swaps, and then discuss the benefits and challenges of debt-for-nature swaps in addressing environmental concerns.

The defining difference of third-generation debt-for-nature swaps

The defining difference in post-Covid swaps is that they are significantly larger than the historic average. If you compare the average conservation funds generated by a swap after 2020, to those before, the recent swaps are more than ten times larger. An analysis of data from Carbon Brief shows that, adjusted for inflation, the average debt-for nature swap before 2020 generated $16,871,000 in conservation funds, while the average swap after 2020 generated approximately $172,500,000 in conservation funds ("Q&A: Can debt-for-nature 'swaps' help", 2024). The major contributor to this size difference is the use of the credit-enhanced debt-for-nature swap. Five of the six recent swaps through the end of 2024 all but Peru may be considered credit-enhanced. There are three main factors that appear to have enabled this significant increase in these credit-enhanced swaps: they focus on debt that is owed to banks rather than other countries; they use commercial insurance and guarantees from public organizations to create highly rated bonds; and they focus on large segments of debt to minimize transaction costs.

Constructed with data from "Q&A: Can debt-for-nature 'swaps' help tackle biodiversity" and "Consumer Price Index Data from 1913 to 2024."

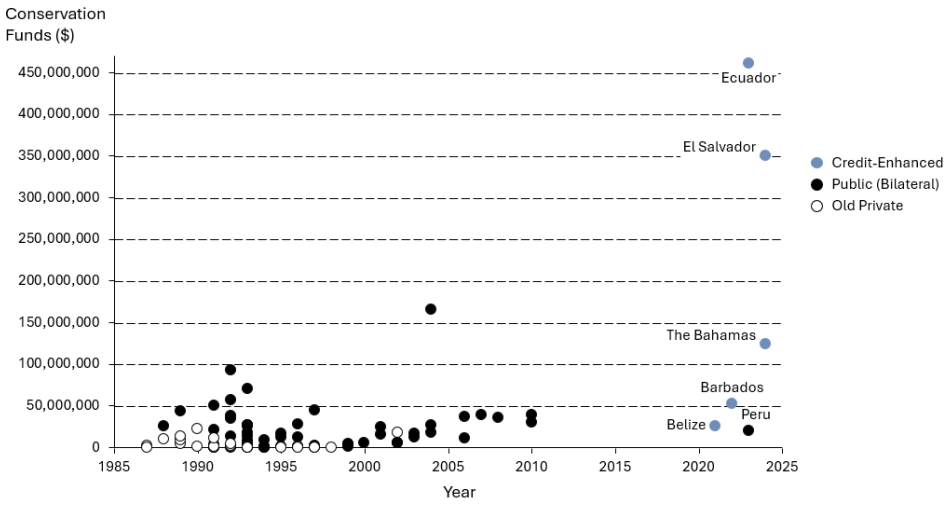

Figure 2. Conservation funds generated from LAC debt-for-nature swaps, inflation adjusted

First, credit-enhanced swaps focus on private, rather than public, debt. Private debt, also known as commercial debt, is owed to large international banks and can be traded among investors. Public debt, on the other hand, is owed directly to other countries. The graph below, constructed with data from the Global Debt Database, demonstrates that commercial debt owed by various Latin American countries in 2022 averaged at around 30% of debt, whereas public debt (labeled "Foreign official") accounts for about 20%. This means that private swaps have a significantly larger pool of debt to tap into today. In the past, however, focusing on public debt was seen as the way to access more funds. This likely made sense for the time; the graph below shows that in 2001, for instance, private debt in the same selected countries accounted for 22% of the total debt, whereas public debt accounted for almost 30%. However, the advantages of using private debt today, as opposed to public debt, can be evidenced by the correlation with significantly higher conservation funds generated than public swaps and historic private swaps. An analysis of Carbon Brief's data shows that, adjusted for inflation, public swaps, including the recent Peru swap, generated an average of $22,987,000 in conservation funds; historic private swaps generated an average of $4,305,000 in conservation funds. New private swaps have generated approximately $202,900,000. While the move to public swaps in the 1990s may have seemed the best way to increase swap funds, it may be that greater returns now lie in private debt.

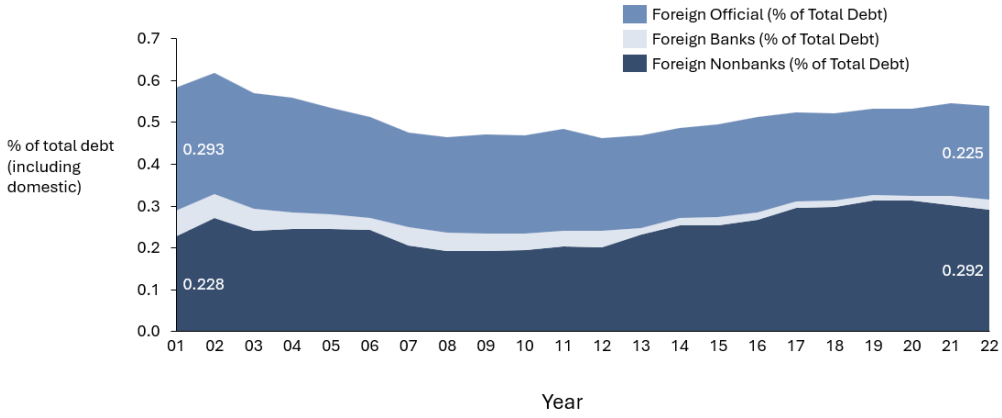

Figure 3. Major sources of foreign debt for LAC countries, as a percent of total debt for 25 LAC Countries tracked by the IMF

Analysis of data from Global Debt Database

A second difference in modern swaps, and a contributing reason for why modern private swaps resulted in more conservation funds than historic private swaps, are that they make use of insurance to create highly rated bonds that generate savings from lower interest rates. Overall, Latin American and Caribbean countries struggle with low credit ratings. The average S&P rating for the region is 'BB'—a score below investment grade (Mukherji & Joydeep, 2023). Many countries in Latin America fall within the "junk bond" category. This score reflects the economic outlook of the countries and their history of payments. Low credit ratings decrease investors' confidence that they will receive the full timely re-payment of their bonds and in turn leads investors to require higher interest payments. However, when debt-for-nature swaps include guarantors that can vouch for these countries and put dollars behind the deal--effectively ensuring that investors will get paid, despite a country's overall low credit score—they can create loans that have relatively low interest payments. All modern, private debt-for-nature swaps in Latin America used insurance and other guarantees to strengthen the deals. Some of these were general guarantees, while others focused on specific risks, like political instability or natural disasters. For example, Ecuador's "Galapagos Bond," which was part of the largest debt-for nature swap in history, was backed by a credit guarantee from the IDB and had political risk insurance (Jones and Campos 2023). For a country that received a Fitch credit rating score of CCC+ in 2023, this was vital to making the bonds investment-grade (Fitch Affirms Ecuador, 2024).

Third, modern private swaps have made scale a priority by targeting large sections of debt. A country's debt can be sold off to different buyers and institutions at various rates; piecing these various sources together can be difficult. However, modern swaps have gravitated towards large groups of debt that can make the transaction costs worthwhile. For example, negotiators in Belize's 2021 swap targeted the country's "superbond." This superbond was a single Eurobond worth $553 million

and comprising all of Belize's external commercial debt ("Case Study: Belize Blue Bonds", 2023) While these large groupings of debt do not always exist, prioritizing their restructuring or swap allows negotiators to scale the overall process and more efficiently generate conservation funds.

Summary of the six most recent swaps

To grasp the impact of the new wave of debt-for-nature swaps, it is helpful to delve deeper into the six post-COVID swaps that have happened in Latin America and the Caribbean: Belize, Barbados, Ecuador, Peru, El Salvador, and the Bahamas.

Ecuador's 2023 debt-for-nature swap is the largest swap yet. The deal revolved around Ecuador's $1.6 billion USD in commercial debt. Through a bond mechanism named the "Galapagos Bond," Ecuador has been able to exchange its loan and now adopt a $656 million bond. The difference in loan amounts, $450 million, which were previously going to debt service payments to now be directed to the Galapagos Life Fund (Miranda, 2023). The exchange was supported by an Inter-American Development Bank guarantee of $85 million, as well as political risk insurance from the US Development Finance Corporation of $656 million (Miranda, 2023). The environmental commitment by Ecuador included the Reserva Marina Hermandad, which covers 60,000 square kilometers of ocean ("Ecuador Completes", 2023).

A more recent swap occurred in El Salvador in October 2024, in protection of the Rio Lempa watershed ("World's Largest Debt Conversion," 2024). El Salvador repurchased $1.0131 billion of its bonds at a discount. It used a loan through JPMorgan to fund a special purpose vehicle, a flexible financial construct, that allowed it to then issue notes that would raise 1 billion dollars, at a lower interest rate. The lower interest rate was partially made possible by the US International Development Finance Corporation, which provides $1 billion of political risk insurance. $200 million of a standby letter of credit was also provided by the Development Bank of Latin America and the Caribbean. In total, the restructuring will allow El Salvador to save more than $352 million. $350 million will go to the Rio Lempa Conservation and Restoration Program spanning the next 20 years. In addition to the monetary benefits of the swap, El Salvador has also agreed to other provisions. These include approving a National Integrated Water Resources Plan and enhanced protocol on water ("World's Largest Debt Conversion", 2024).

Unlike other modern swaps, Peru's swap in 2023 reflects much of the second-generation bilateral debt-swaps. The swap was negotiated between the US, Peru, Conservation International, the Nature Conservancy, Wildlife Conservation Society, and the World Wildlife Fund, an admittedly large group for a public swap. However, most of the swap, $15 million, was between the US and Peru, while $3 million was supplied by the NGOs. The bilateral part of the deal was negotiated under the Tropical Forest and Coral Reef Conservation Act (TFCCA), the successor of the Tropical Forest Conservation Act (TFCA), under which the bulk of second-generation swaps were negotiated ("United States $20 Million," 2023). The intended result of the swap will be greater protection of the Peruvian Amazon, and the protection of 10% of the country ("Statements: Environmental Organizations," 2024).

A clear priority of debt-for-nature swaps today is the focus on oceans. Three of the six most recent swaps, Belize, Barbados, and The Bahamas, were aimed at protecting oceans and two were executed through the Nature Conservancy's "Blue Bonds for Ocean Conservation." The strengthening interest in ocean protection shines a spotlight on many Caribbean countries that often deal with smaller budgets and resources.

A recent example is the November 2024 swap in the Bahamas, negotiated by The Nature Conservancy and the Inter-American Development Bank. Through this deal, the Bahamas renegotiated $300 million of its debt to generate savings of $124 million for marine conservation. The funds will go towards mangrove protection, which will be aided by national Mangrove Management Plan ("The Bahamas Launched Debt," 2024). Additionally, in 2021, Belize negotiated a swap centered around a $553 million superbond, aimed at protecting the marine areas around Belize ("Case Study: Belize Blue Bonds", 2023). It resulted in an endowment that is set grow to $92 million and approximately $4 million invested a year into conservation. The notable feature of the swap was how its scale was enabled by a blue bonds structure, issued by Credit Suisse. These funds enabled the repurchase of the superbond at a deep discount. ("Case Study: Belize Blue Bonds", 2023). Furthermore, Barbados' 2022 swap funds $1.5 million a year for grants, through the Barbados Environmental Sustainability Fund, and starts an endowment that is set to grow to $27 million by 2037 ("Case Study: Barbados Blue Bonds," 2023). A commitment to protect up to 30% of Barbados' ocean is baked into the deal, which would be protected by a thoroughly developed Marine Spatial Planning approach. ("Case Study: Belize Blue Bonds", 2023).

The promise and challenges of debt-for-nature swaps

Debt-for-nature swaps have made an impressive return in the field of Latin American sustainable finance. After ten years of no swaps in the region, they have come back with even greater impacts and have generated significantly larger conservation funds than historical swaps. These new swaps hold exciting promises for the region but certainly come with challenges as well. The greatest benefits of pursuing debt-for-nature swaps, particularly credit-enhanced swaps, are that they generate large investments in conservation funds and are appealing across the political spectrum for both indebted nations and lenders. However, these swaps also come with challenges, including a lack of transparency, greenwashing, and the still-developing institutional strength in debt offices.

The benefits of debt-for-nature swaps

First, debt-for-nature swaps show promise for being able to generate large amounts of conservation funds for Latin America. Data from Carbon Brief shows the total amount of conservation funding generated by the six recent debt-for-nature swaps is more than $1 billion, concentrated in just the six countries where the swaps occurred ("Q&A: Can debt-for-nature 'swaps' help", 2024). Additionally, the shift to private swaps can tap into the resource of individual investors who would like to prioritize ESG (Environmental, Social and Governance) projects in their portfolios. One Morgan Stanley survey showed that that 40% of respondents were "very

interested in sustainable investing," and 80% "believe that it is possible to balance market rate financial returns with a focus on sustainability" (Individual Investors' Interest", 2024).

Debt-for-nature swaps also carry appeal across the political spectrum, helping them be an effective sustainable finance tool that is less subject to changes in the global political environment. In fact, these swaps seem to be especially popular with conservative governments in Latin America; there is a notably larger number of swaps corresponding with right-leaning administrations, as illustrated in the chart below.

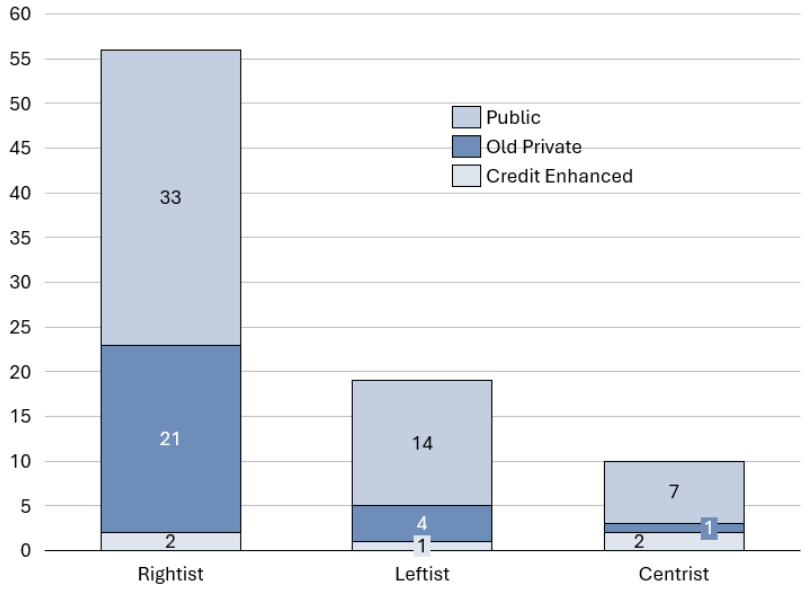

Figure 4. Political leanings of recipient leaders during years in which swaps occurred

Analysis of data from Herre, Bastian, "Identifying Ideologues."

One explanation for this right-ward lean is the appeal that these swaps have from a fiscally conservative perspective. The swaps allow a leader to shrink a country's debt while furthering generally popular projects of environmental protection. In Latin America, research points to sustainability and concern about climate change being cross-party issues; climate skepticism does not appear to correlate strongly with political ideology (Spektor et al., 2023). Thus, if one supposes that environmental concern is constant across political ideologies, then it makes sense for fiscally conservative leaders to appease this issue using funding avenues that do not require significant additional investment. Overall, the relatively diverse spread of swaps across ideologies, even when considering the type of swaps completed (bilateral, private, or credit enhanced) is a positive indicator for debt-for-nature swaps.

The challenges of debt-for-nature swaps

The primary critique of debt-for-nature swaps is that they are not transparent enough. Several organizations, such as the Climate Action Network, have spoken against the lack of information publicly available before, during, and after swaps occur ("Climate Action Network, 2023; "Financing the 30x30 agenda," 2022). They suggest that this lack of transparency prevents the important inclusion of stakeholders and does not allow observers to verify if recipient countries are receiving the best deal possible. A report signed by groups like Greenpeace and various fishing organizations argues that the secrecy of debt swaps is part of their nature and is needed to prevent "unpredictable effects on bond markets," particular for swaps from The Nature Conservancy ("Financing the 30x30 agenda," 2022). Therefore, they further, these swaps should not be pursued. They claim that the lack of transparency shrouds other issues, such as subsidiaries in these negotiations being in tax havens ("Financing the 30x30 agenda," 2022).

Ecuador's swap, which protects large sections of the Galapagos, has garnered a significant amount of attention for not being transparent. A complaint was filed by 24 groups and individuals to the Independent Consultation and Investigation Mechanism (MICI), an IDB office (Repetto, 2024). The filers, which were based in the Galapagos and Quito, allege that there was a "lack of accessible and relevant information about the program," specifying that communities in the Galapagos were not properly informed about "conservation initiatives and projects that the operation plans to implement through the conservation fund" (Repetto, 2024, p. iv). While it is difficult say if the Ecuador swap was transparent per IDB's policy, the fact that advocates decided to file a complaint signals possible gaps in communications with the public.

An additional critique of debt-for-nature swaps is that they fail to achieve significant conservation goals through greenwashing and distracting from other funding avenues. There is a real possibility that these swaps are falsely advertised and that they could be used to cover illegitimate debt.

Recent debt-for-nature swaps are advertised as an innovative way for investors to support the conservation efforts of the recipient country, in addition to alleviating part of their debt burden. Terms like "green bonds" and "blue bonds," are often used to describe these investment instruments, such as is in the case of Belize and Barbados which are both part of the "blue bonds for nature conservation" model at The Nature Conservancy. However, these terms have technical definitions which imply that 100% of investor's funds are used towards conservation, something that is not true for the swaps, as a portion goes towards transaction costs, other fees, and debt savings. Analysts at Barclays have described debt-for-nature swaps packaging as "misleading" ("Barclays", 2023).

Another aspect of greenwashing is that the swaps do not just fail to meet their advertised commitments but actively work with illegitimate debt. Illegitimate debt is debt that is "irregular, inappropriate, irresponsible, dubious, or fraudulent" (Freshnillo, 2023, p. 27). This could be especially prevalent in places with authoritarian

governments or corruption at senior levels. The conventional thinking is that citizens should not be forced to pay back loans, through taxes, which were not made for their benefit. Thus, it is argued that the loans must be outright canceled rather than restructured to accommodate a debt-for-nature swap (Climate Action Network, 2023). However, one perspective suggests that debt swaps could be a means of reparation for illegitimate debts. There has been a proposal, for instance one regarding illegitimate debt that went to a dictatorship in Indonesia, to use funds saved from a debt swap of illegitimate money to fund compensation funds for victims (Freshnillo, 2023). A similar approach could be considered for illegitimate debts that are used in debt-for-nature swaps to benefit indigenous communities in neglected nature reserves.

The third challenge that faces debt-for-nature swaps is that there is an imbalance of institutional knowledge. Recent swaps revolve around negotiations between very experienced and wealthy banks and multinational nonprofits, and finance offices of developing countries. These offices which represent their country in negotiations may be working with smaller teams, fewer resources, and less developed institutional knowledge. As a result, it becomes more difficult to represent the best interests of their country in negotiations, it may be difficult to carry out the complex financial transactions that are decided upon for the swap, and the country may be susceptible to fall back into debt challenges.

A study by the IDB found that there were several challenges around Latin America in debt management offices. They found that some of the main shortcomings were a lack of debt management committees, which help manage macro-fiscal decisions, a lack of a medium-term debt management strategy, and the documentation of lending procedures. However, there was significant variation across the region. The Caribbean was more often lacking in these measures. These countries marked lowest on IDB's scale capacities for "Debt borrowing and other debt related activities" and "Debt strategy and sustainability" (Prats et al. 2022, p. 9). There is also a noted correlation between less equipped debt management offices and smaller economies. This poses a challenge for the growing prevalence of the Blue Bonds, focused on marine conservation, which have been particularly prevalent in small Caribbean nations.

Conclusion

In conclusion, recent debt-for-nature swaps are a compelling tool for furthering sustainability funding in Latin America. While past swaps were criticized for generating only small amounts of conservation funds, the recent credit enhancement model has proven successful in unlocking significantly larger amounts of funds, on the range of around 10 times more than past swaps. With five of the six most recent swaps using the credit enhancement model, the total amount of funding in the region has been impressive. However, there are still some challenges facing debt-for-nature swaps, most importantly the lack of transparency. Without transparency regarding swap negotiations, there may be backlash from local organizations who feel excluded and from international investors who expect information.

It is important to note that the analysis provided in this paper depended heavily on publicly available sources. And while the data was valuable, it is difficult to confirm if they were comprehensive. Additionally, a challenge of sustainability research in general is the use of titles for various projects. As the words we use for sustainability, environmentalism, and climate shift in meaning and take on official definitions, it can be challenging to maintain a consistent approach to how projects are categorized. For these reasons, the research presented here should be taken as relative and not exact.

Further research is still required in the field of debt-for-nature swaps to fully understand how they can better aid global conservation, and it would be interesting to see how the larger credit-enhancement swaps affect the financial wellbeing of a country. For instance: do these swaps lead to higher economic growth as a result of debt payment reductions and greater employment and tourism from the conservation projects? Or, does the large size of the swaps now introduce the risk of inflation? Furthermore, could the use of debt-for-nature swaps lead to more poorly negotiated initial debt terms in the future and less initial conservation work driven by countries, since they may depend on the future possibility of debt-for-nature swaps to solve both their debt and environmental challenges? These questions, and many more, will require time and transparency to fully flesh out.

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