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TECHNICAL REPORT

NAVIGATING THE TIDE

Strategic Approaches to Combatting Aquatic Litter

Sebastian N. Singh

UVA | FRANK BATTEN SCHOOL of LEADERSHIP and PUBLIC POLICY

KEEP AMERICA BEAUTIFUL

PREPARED FOR

David Scott, Ph.D.
Senior Vice President, Impact and Analytics
Keep America Beautiful

PREPARED BY

Sebastian Singh
Master of Public Policy Candidate
Frank Batten School of Leadership and Public Policy
University of Virginia

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DISCLAIMER

The author conducted this study as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, the University of Virginia, Keep America Beautiful, or by any other agency.

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EXECUTIVE SUMMARY

THE PROBLEM

Aquatic litter is categorized into three main types: land-based, ocean-based, and disaster-based debris. Land-based debris, constituting the majority, originates from human activities on land and includes everyday items like plastic bags and bottles. Ocean-based debris arises from activities at sea, such as discarded fishing gear, while disaster-based debris results from natural events like floods. This report focuses on land-based litter, which accounts for 80% of all aquatic debris, due to its significant contribution to pollution and the challenges in addressing water-based litter. Over 359 million tons of plastic are produced annually, with a significant portion ending up in oceans. Addressing inadequate waste management, cultural acceptance of single-use plastics, and lack of public education is crucial for reducing plastic pollution. Aquatic litter has environmental, economic, and public health impacts, disproportionately affecting marginalized communities, including Environmental Justice communities, BIPOC, and low-income groups.

APPROACH

The report adopts a comprehensive approach, focusing on evidence of existing solutions to tackle plastic and microplastic contamination. It reviews scientific literature to summarize key solutions implemented in various contexts, including policy options like bans, extended producer responsibility (EPR), and deposit recovery systems (DRS), as well as technologies for managing plastics and microplastics. The report evaluates the efficacy, costs, and suitability of these solutions under different conditions, aiming to inform sustainable and cost-efficient approaches to the plastic problem. By analyzing existing solutions and best practices, the report aims to form the basis of policy alternatives recommended for addressing plastic and microplastic contamination. This approach ensures that the recommendations are grounded in evidence and tailored to the specific challenges and conditions of the issue at hand.

KEY FINDINGS

After conducting a comprehensive review and analysis of the issue of aquatic litter, particularly focusing on plastic pollution in waterways, the report presents three policy alternatives for reducing this environmental challenge:

1. Community Education & Awareness: This alternative aims to raise awareness and advocate for systems like Extended Producer Responsibility (EPR) and Deposit Recovery Systems (DRS) to reduce litter and promote recycling. The campaign will involve developing educational materials, organizing workshops and events, and engaging with local communities and stakeholders.
2. Shifting Social Norms: This approach focuses on organizing regular cleanups of waterways and coastal areas to shift social norms regarding littering. The initiative will include educational

tents at cleanup events to raise awareness about the impacts of litter and promote responsible waste disposal practices.

3. Aquatic Litter Capture Technologies: This alternative involves the deployment of Seabins and litter booms in key locations to capture floating debris and prevent it from polluting waterways. The initiative will be spearheaded by Keep America Beautiful (KAB), in collaboration with local authorities and businesses.

The alternatives are evaluated based on four criteria:

1. Effectiveness: Assessed based on their ability to achieve significant reductions in aquatic litter, measured through data on litter levels before and after the implementation of strategies.
2. Cost: Examines the total financial investment required for planning, implementation, and ongoing maintenance of the programs.
3. Feasibility: Evaluates the practicality of implementing the solutions, considering factors such as community support, resource availability, and infrastructure capability.
4. Equity: Assesses whether the impacts, costs, and benefits of the initiatives are fairly distributed across different populations, with a focus on ensuring that marginalized communities are not disproportionately affected.

RECOMMENDATION

Based on the analysis of the policy alternatives to address aquatic litter, I recommend the implementation of the Shifting Social Norms policy. This policy stands out for its feasibility, equity, and cost-effectiveness while maintaining a reasonable level of effectiveness in reducing aquatic litter. The initiative capitalizes on community engagement to foster responsible waste disposal practices. It is highly feasible, leveraging existing networks and resources with a score of 30 out of 35, and encourages volunteer participation, which helps keep operational costs low, ranging from $110,000 to $290,000. This policy's focus on education and awareness-raising ensures equitable distribution of benefits, scoring 13 out of 15 in equity, contributing to the overall well-being of the community. With nearly the most aggressive amount of litter reduction, -24.87% to -25.02%, and its potential for long-term behavioral change, it proves a sustainable and impactful choice.

IMPLEMENTATION

The Shifting Social Norms initiative, led by Keep America Beautiful, aims to address aquatic litter through a pilot program focusing initially on urban settings. The one-year program begins with three months of planning and coordination, engaging stakeholders and utilizing GIS technology to map litter hotspots. Volunteer recruitment and training occur in the following three months, leveraging diverse outreach channels. The next three months are dedicated to regular cleanup events, educational activities, and data collection, with a focus on small plastics and cigarette butts. The final phase involves evaluating the program's effectiveness and reporting on its impact, with an emphasis on sustainability and long-term community engagement.

INTRODUCTION

PROBLEM STATEMENT

Aquatic litter, which poses a critical threat to the environment, is poorly mitigated in the United States with 20 million to 1.8 billion pieces of plastic across U.S. coastlines (Allsopp et al., 2006). The accumulation of debris can disrupt food chains, alter habitat structures, and introduce toxins into the environment, leading to negative impacts that manifest throughout the ecosystem. In addition, aquatic litter can result in direct and indirect economic costs and contaminate seafood that millions depend on as their principal source of dietary protein (NOAA, 2021; Landrigan et al., 2020).

MOTIVATION

Keep America Beautiful seeks to deepen their understanding of aquatic litter, including both known aspects and areas where knowledge is lacking. Additionally, there was a desire to explore potential strategies that Keep America Beautiful could employ to address this pressing environmental issue. This report aims to provide a comprehensive overview of the current state of aquatic litter, particularly focusing on plastic pollution in waterways, and to present evidence-based policy alternatives that Keep America Beautiful could consider implementing to mitigate the impacts of this problem on aquatic ecosystems and surrounding communities.

ROADMAP

This report follows a structured approach to address the issue of aquatic litter, particularly focusing on plastic pollution in waterways. It begins by defining the problem. The report then adopts a comprehensive approach to review existing solutions, including policy options as well as technologies for managing macroplastics and microplastics.

The analysis portion of this report begins by establishing and defining the four criteria on which the policy alternatives will be evaluated. Key findings from the analysis present three policy alternatives. Once each of the above alternatives is evaluated, the findings are summarized in a multidimensional outcomes matrix. The best policy alternative is recommended and implementation steps are outlined. Supporting cost calculations and additional information can be found in the appendices.

CLIENT OVERVIEW

ORGANIZATIONAL BACKGROUND

Keep America Beautiful (KAB) is a leading national nonprofit organization with a mission to inspire and educate individuals to take action every day to improve and beautify their community environment. Established in 1953, KAB has been at the forefront of environmental stewardship, focusing on ending littering, improving recycling, beautifying America's communities, and restoration and resiliency. Although KAB focuses on cleaning up the environment and public spaces, on a deeper level, their mission is to instill a deep understanding about the synergy of environmental health and social well-being–an understanding that collective action on environmental issues in our communities can bring about change that benefits all of us. The organization collaborates with millions of volunteers, corporate partners, and government agencies to provide solutions that create clean, green, and beautiful public spaces.

KAB is committed to advancing its mission through four core pillars: ending littering, enhancing recycling practices, beautifying public spaces, and supporting resilient communities. The organization underscores the critical role of education in driving behavioral change, implementing educational programs and campaigns that highlight the environmental and social advantages of maintaining clean and aesthetically pleasing surroundings. KAB actively seeks collaborations with government agencies, businesses, and community organizations, fostering partnerships that are instrumental in addressing environmental challenges and beautification efforts. These collaborations are evident in flagship programs such as the Great American Cleanup, America Recycles Day, and the Cigarette Litter Prevention Program.

Moreover, KAB engages in research and data collection to gain insights into littering and waste generation patterns, informing the development of targeted programs and advocacy efforts. A notable initiative was the 2020 litter study, which aimed to understand the national scale of litter, characteristics of common litter items, trends in littering behavior, and potential solutions. The analysis that follows will augment KAB's research-focused initiatives, offering strategic guidance to shape policy and organizational endeavors.

KAB also extends community grants and support to local affiliates, empowering them to execute projects that resonate with the organization's mission. As such, KAB is positioned to provide funding to implement solutions discussed in subsequent sections of this report. They mobilize communities to collectively prevent and clean up litter. KAB collaborates with individuals, community groups, businesses, and legislators to address littering issues, advocating that individual participation in cleanup efforts can foster community behavioral change. KAB's network of over 700 affiliates delivers impactful, innovative, and locally tailored solutions to litter challenges, providing resources such as a litter volunteer organizing guide, information about programs like the Cigarette Litter Prevention Program and Great American Cleanup Program, and litter cleanup kits.

Furthermore, KAB is dedicated to improving recycling practices, asserting that effective recycling contributes to a more self-reliant, beautiful, and sustainable America. KAB's recycling programs focus on education and collaboration with municipal, school, business, and community leaders to enhance recycling processes and ensure proper recycling practices. The organization publishes articles to promote recycling and sustainable behaviors and provides guidelines for recycling at home, work, and on the go (i.e. Sustainable Back-to-School, Make Your Labor Day Eco-Friendly). Through its sister website, berecycled, KAB offers information on local recycling practices and guidance on recycling specific materials.

PROBLEM ALIGNMENT WITH ORGANIZATIONAL GOALS

The control and prevention of aquatic litter is a natural extension of KAB's core goals and mission. KAB's initiatives have traditionally focused on creating clean, green, and beautiful communities by reducing waste, preventing litter, and encouraging recycling. Addressing aquatic litter aligns with these objectives by expanding the organization's environmental stewardship endeavors to specifically include aquatic ecosystems.

First, aquatic litter is a critical aspect of KAB's goal to end littering. By focusing on the sources of aquatic litter, such as land-based waste mismanagement and littering behaviors, KAB can address one of the primary contributors to this global problem. Initiatives aimed at reducing litter in urban and coastal areas directly contribute to decreasing the amount of waste that eventually enters aquatic environments. Second, KAB's efforts to improve recycling are closely linked to the prevention of aquatic litter. By promoting better waste management practices and increasing recycling rates, KAB helps reduce the volume of plastic and other materials that can become aquatic litter. Encouraging the use of recyclable and reusable materials also supports this goal by minimizing the overall production of waste. Moreover, the presence of litter in waterways and coastal areas detracts from the natural beauty of these environments. KAB's goal of beautifying communities extends to aquatic and coastal areas, where clean-up initiatives can restore the aesthetic and ecological integrity of these habitats. Lastly, KAB's approach to environmental stewardship involves engaging communities in taking collective action. The control and prevention of aquatic litter provide opportunities for community involvement through clean-up events, educational programs, and advocacy efforts. By mobilizing volunteers and stakeholders, KAB fosters a sense of shared responsibility for protecting aquatic ecosystems.

ROLE IN ADDRESSING THE PROBLEM

KAB plays a critical role in addressing the problem of aquatic litter through a comprehensive approach that encompasses education, advocacy, direct action, research, and innovation. By leveraging its extensive network of volunteers, partners, and stakeholders, KAB can implement effective strategies to combat aquatic litter at multiple levels.

Through various educational programs and campaigns, KAB can raise awareness about the sources, impacts, and solutions to aquatic litter. These initiatives aim to change individual behaviors by encouraging responsible waste disposal, promoting the use of reusable and recyclable materials, and fostering a culture of environmental stewardship. KAB can also develop educational materials and resources for schools, communities, and businesses to spread knowledge and best practices for preventing aquatic litter. At the same time, they also actively advocate for policies and regulations that help prevent litter. In the context of aquatic litter, this can include supporting legislation that addresses single-use plastics, improves waste management infrastructure, and encourages the adoption of sustainable materials. Moreover, by working with local, state, and federal governments to influence policy decisions and to promote the implementation of effective waste management systems, they can reduce the flow of litter into aquatic environments.

Additionally, KAB can also use the power of community engagement by organizing and supporting clean-up events in coastal areas, rivers, and waterways. These events not only remove existing litter from aquatic environments but also serve as educational opportunities that inspire participants to take further action in their daily lives. By mobilizing volunteers and fostering partnerships with local organizations, KAB can create a collaborative effort to address aquatic litter at the grassroots level.

Another important role for KAB lies in research initiatives that aim to better understand the sources, pathways, and impacts of aquatic litter. By collaborating with academic institutions, government agencies, and other organizations, KAB can contribute to the development of innovative solutions and technologies for aquatic litter prevention and removal. This research can inform KAB's strategies and programs, ensuring that they are based on the latest scientific knowledge and best practices.

KAB recognizes that addressing aquatic litter requires a collaborative approach. The organization partners with a wide range of stakeholders, including businesses, non-profits, government agencies, and international organizations, to leverage resources and expertise. These partnerships can enable KAB to implement comprehensive strategies that address aquatic litter at different stages of its lifecycle, from production and consumption to disposal and recovery.

LIMITATIONS IN ADDRESSING THE PROBLEM

While KAB has been instrumental in advocating for consumer responsibility and policy changes to tackle the issue of aquatic litter, it is important to recognize the limitations of their approach. The reduction of aquatic litter cannot be fully achieved without addressing the production side of the problem and transition to a more circular economy.

The issue of aquatic litter is not solely a result of consumer behavior; it is deeply rooted in the production practices of industries that create disposable packaging and single-use products (Chen et al., 2021). The historical focus on consumer responsibility has often overshadowed the need for systemic changes in how products are designed, produced, and disposed of (Akenji, 2014). The reality is that even with significant improvements in waste management and recycling, the continuous growth in the production of plastic and other materials contributes to the persistence of aquatic litter.

A more sustainable solution to the problem of aquatic litter involves transitioning to a circular economy, where materials are kept in use for as long as possible, and waste is minimized (Kirchherr et al., 2017). This approach requires a fundamental shift in production practices, moving away from the linear "take-make-dispose" model to a system where products and materials are designed for reuse, repair, and recycling (Adam et al., 2017). However, achieving a circular economy is a complex challenge that involves not only changes in industry practices but also in consumer behavior, policy frameworks, and global supply chains.

To effectively tackle the problem of aquatic litter, there is a need for increased corporate accountability in reducing the production of waste (Dauvergne, 2018; Landon-Lane, 2018). This includes investing in sustainable materials, redesigning products for reuse and recyclability, and supporting infrastructure for effective waste management. Corporate initiatives that claim to promote sustainability must be scrutinized to ensure they are not merely greenwashing but are genuinely contributing to the reduction of aquatic litter.

KAB's efforts in education, advocacy, and community engagement are crucial in raising awareness and promoting responsible waste management. However, their influence on the production side of the equation is limited. As a nonprofit organization, KAB does not have direct control over the production practices of industries that contribute to aquatic litter. While KAB can advocate for policy changes and corporate responsibility, the implementation of a sustainable litter solutions requires a concerted effort from businesses, governments, and consumers alike.

BACKGROUND

COMPARATIVE SCALE & SCOPE

This section examines the sources of aquatic litter, a significant environmental challenge affecting various ecosystems. We categorize the sources into three main types: land-based, ocean-based, and disaster-based debris. Land-based debris, which constitutes the majority of aquatic litter, originates from human activities on land, including everyday items like plastic bags and bottles. Ocean-based debris arises from activities at sea, such as discarded fishing gear and waste from ships. Disaster-based debris results from extreme natural events that introduce large quantities of litter into waterways and oceans.

Plastic pollution, including macroplastics, microplastics, and nanoplastics, and also explored in brief . Additionally, we discuss the challenges of plastic production and waste management, highlighting the importance of addressing plastic leakage into aquatic ecosystems. This section serves as a foundation for understanding the origins and consequences of aquatic litter, setting the stage for discussions on mitigation strategies in subsequent sections of the report.

Sources of Aquatic Litter

The National Oceanic and Atmospheric Administration (NOAA) categorizes litter into three main types: land-based, ocean-based, and disaster-based (NOAA, 2023). Land-based litter primarily originates from human activities on land, which eventually contributes to aquatic litter. This type of debris results from the intentional or accidental littering of everyday items such as plastic bags, bottles, straws, cigarette butts, and food containers. These items can be swept into marine environments through stormwater runoff that flows into streams, rivers, and eventually into larger bodies of water. Land-based debris includes not only items left behind at beaches but also improperly disposed of waste that finds its way into aquatic ecosystems. Ocean-based debris, on the other hand, is generated from activities at sea. This category includes items that are discarded, lost, or damaged from ships, boats, and offshore platforms. Common types of ocean-based debris include fishing gear like nets, lines, and traps, as well as everyday items like plastic bags and bottles that are dumped or accidentally lost overboard. Additionally, large shipping containers filled with consumer goods that fall off vessels contribute to this form of marine debris. Disaster-based debris is a result of extreme natural events such as hurricanes, tsunamis, and floods, which can rapidly introduce large quantities of debris into waterways, oceans, and the Great Lakes. The force of these disasters can transport a wide range of objects, including household items, vehicles, and structural components, far into aquatic environments. Moreover, maritime accidents, such as overturned vessels, cargo spills, and collisions with infrastructure like bridges, can also lead to significant amounts of aquatic debris.

For the purpose of this report, the focus will be primarily on land-based litter. By weight land-based litter accounts for 80% of all aquatic debris, while water-based litter accounts for less than 20% (UN, 2023; IUCN, 2022). This approach is strategic, as addressing land-based litter can significantly reduce the overall litter entering the aquatic environments. Additionally, the mechanisms of addressing water-based litter are infinitely more complex. Lack of ability to monitor and enforce regulations on water-based industries (i.e. difficulty enforcing illegal dumping on container ships and fishing vessels) makes this problem a considerably difficult one to address (Haarr et al. 2022; Green, 2012). Focusing on land-based litter means neglecting a smaller portion of ocean-based debris, but it allows for a more manageable and impactful approach to reducing aquatic litter.

Composition and Categories of Plastic Pollution

Although the composition of litter across all aquatic environments is unknown, research has explored litter characteristics and trends within waterways (KAB, 2021). Researchers estimate that 25.9 billion pieces of litter were scattered along US waterways. Of these waterways, large perennial waterways had the most litter items per mile with 3,654 litter items per mile on average compared to small perennial and intermittent waterways with only 1,960 litter items per mile on average. However, these intermittent waterways had the most total litter items in aggregate with 13.6 billion litter items. Plastics and cigarette butts compose most litter items along waterways (Figure 1). Of the total litter discarded near United States waterways, 10.9 billion (42.2 percent) were pieces of plastic followed by 4.0 billion (15.4

percent) cigarette butts. The composition of litter was comparable across waterway types for plastics, organics, and tire treads but varied for paper, metal, and cigarette butts.

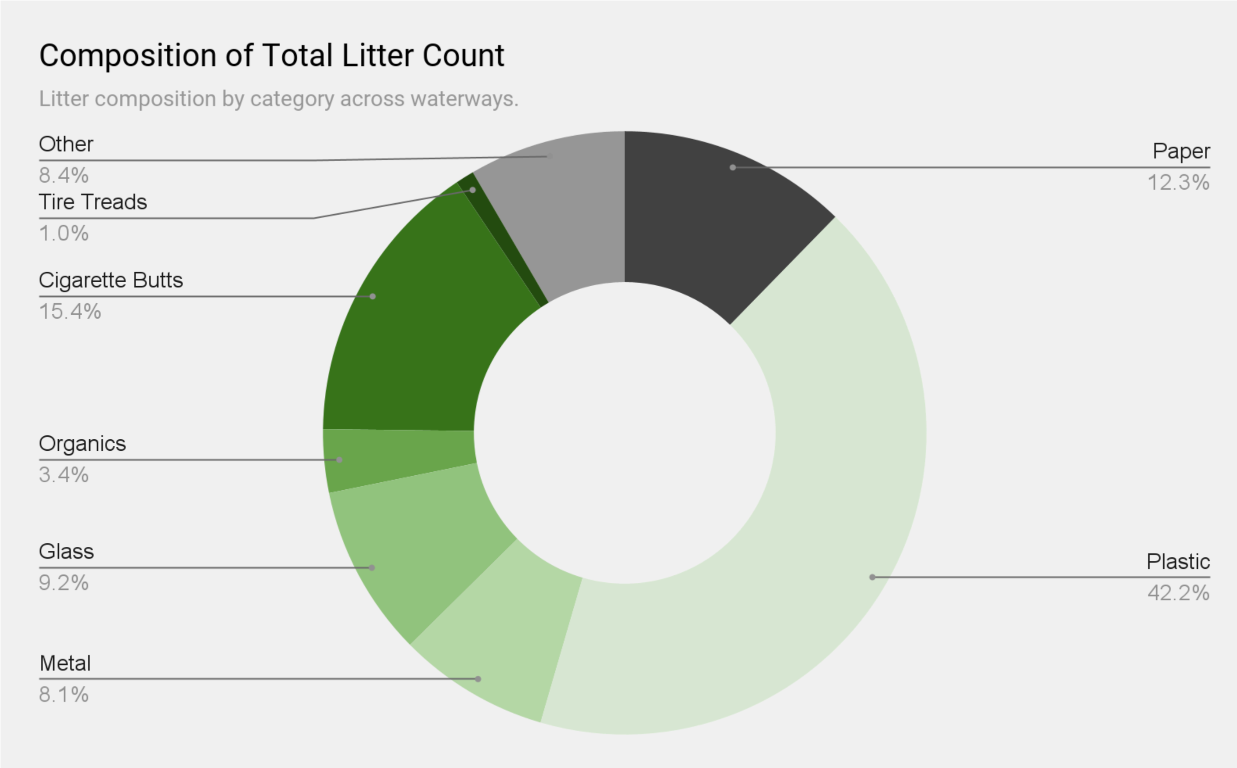

Figure 1. Composition of litter in waterways and aggregate by material groups. Cigarette butts and tire treads were the majority of other litter material group. Therefore, the other material group was subdivided into cigarette butts, tire treads, and others for the above figure. *Source: Burns & McDonnell, Cascadia (2021)*

There are three main categories of plastics found in waterways: Macroplastics, microplastics, and nanoplastics. First, macroplastic pollution consists of plastic items larger than 20 mm, which are highly visible and often considered one of the most concerning types of plastic pollution. This form of pollution has been extensively documented since the 1990s across various habitats. The size of macroplastic debris allows for classification based on its original use, such as packaging, fishing gear, or sewage-related items. Clean-up efforts typically target these larger, more visible items, although the variability in their geographical distribution poses challenges for trend analysis.

The presence of small plastic fragments in the ocean was first noted in the 1970s, but the term microplastics was not coined until 2004, referring to particles greater than 1 micro meter and less than 5 millimeters in diameter (Carpenter & Smith, 1972; Thompson et al., 2004). Initially overlooked in plastic pollution studies, microplastics have gained significant research interest over the past decade due to growing concerns about their impact. Microplastics are classified into primary and secondary sources. Primary microplastics are intentionally produced small particles, used in manufacturing or directly in products such as cleaning agents, cosmetics, and abrasive media (Napper & Thompson, 2020). Secondary microplastics result from the breakdown of larger plastic items or from the wear and tear of products, like tire abrasion or fiber shedding from textiles. Even if the release of larger plastic items were halted, the fragmentation of existing plastics would continue to increase microplastic levels.

Microplastic pollution in the aquatic environment can also originate from sources not typically associated with conventional waste. For example, a standard 6 kg wash of synthetic clothing is estimated to release over 700,000 microplastic fibers (Napper & Thompson, 2016). Additionally, plastic tea bags could release approximately 11.6 billion microplastics and 3.1 billion nanoplastics into a single cup of tea (Hernandez et al., 2019). Tire wear is another significant source, contributing 28% of secondary microplastics to the world's oceans, amounting to 420,000 tons per year. These microplastics can enter the aquatic environment through various pathways, including bypassing wastewater treatment plants, flowing through storm drains, or being carried by air and deposited at sea. However, the impact of plastic pollution extends beyond the oceans. In Lake Erie, plastic particle counts have reached one million parts per square mile, with even higher counts in Lake Ontario (Mason et al., 2014). The Great Lakes are among the regions with the highest recorded densities of microplastics (US Department of the Interior, 2019). Microplastics are more numerous than larger plastic items in aquatic systems but represent a small fraction of total plastic mass. Nonetheless, they are a pervasive component of anthropogenic debris in both marine and freshwater environments (Thompson, 2015).

Finally, nanoplastics, measuring less than 1000 nm, can also originate from primary or secondary sources (Andrady, 2011). Like microplastics, nanoplastics have been relatively neglected in research until recent years, with studies now focusing on identifying their sources. The impacts of nanoplastics are not yet fully understood, but it is likely that all plastics eventually break down into nanoplastic size before complete degradation (Bouwmeester et al., 2015). As a result, the presence and significance of nanoplastics in marine environments are expected to grow in the coming years.

Plastic Production and Leakage

Annually, over 359 million tons of plastic are produced, and forecasts suggest this production could double in the next two decades. A significant portion, more than 40%, of this plastic is designated for single-use items such as plastic bags, cutlery, straws, cups, and food packaging. These products' short-lived applications rapidly lead to large amounts of persistent plastic waste, a fraction of which becomes environmental litter. It is estimated that approximately 8 million tons of mismanaged plastic waste find their way into the oceans each year, with indications that this quantity is on the rise. The majority of this plastic pollution originates from inland sources and reaches the oceans through coastal areas or river systems. Rivers, in particular, have been identified as significant conduits for transporting plastic waste to the oceans, with estimates suggesting they carry between 1.15 and 2.41 million tons of plastic waste into marine environments annually.

Without immediate and sustained action, it is estimated that the annual flow of plastic into the ocean could nearly triple by 2040 (Lau et al., 2020). This prediction is indicative of a lack of proper waste management systems and techniques. Currently, only 9% of all plastics ever produced have been recycled, primarily through mechanical recycling methods. Among OECD and non-OECD regions, the

United States consistently recycles plastic waste less than its counterparts, recycling only 4% (OECD, 2022). Moreover, Law et al. (2020) estimate that more than half of all plastics collected for recycling in the United States are shipped abroad and almost 90% of these plastics were exported to countries that do not effectively manage, recycle, or dispose of plastics. The majority of plastic waste, however, ends up in landfills, which vary in quality. In developed countries, waste is often disposed of in sanitary landfills, considered "managed" disposal sites. In contrast, developing countries frequently rely on semi-controlled dumps, where contaminants, including plastics, can leak into the environment.

HISTORY OF THE PROBLEM

The history of human civilization is often defined by the materials that shaped its progress, such as the Stone Age, the Bronze Age, and the Iron Age. Today, modern society has arguably entered the Plastic Age (Thompson et al., 2009). Plastics, which have been around for just over a century, have revolutionized many aspects of our lives due to their versatility and durability (Geyer et al., 2017). The first synthetic plastic, Bakelite, was invented in the early 20th century, but it wasn't until after World War II that the mass production of plastics truly began. By the 1950s, annual production was around 5 million tons, and this figure skyrocketed to around 440 million tons by 2018 (Figure 2). Plastics are made from synthetic or semi-synthetic organic polymers, often derived from fossil oil or gas feedstocks. The wide variety of polymers and additives has made plastics a ubiquitous material in healthcare, agriculture, transport, construction, and packaging (Napper & Thompson, 2020).

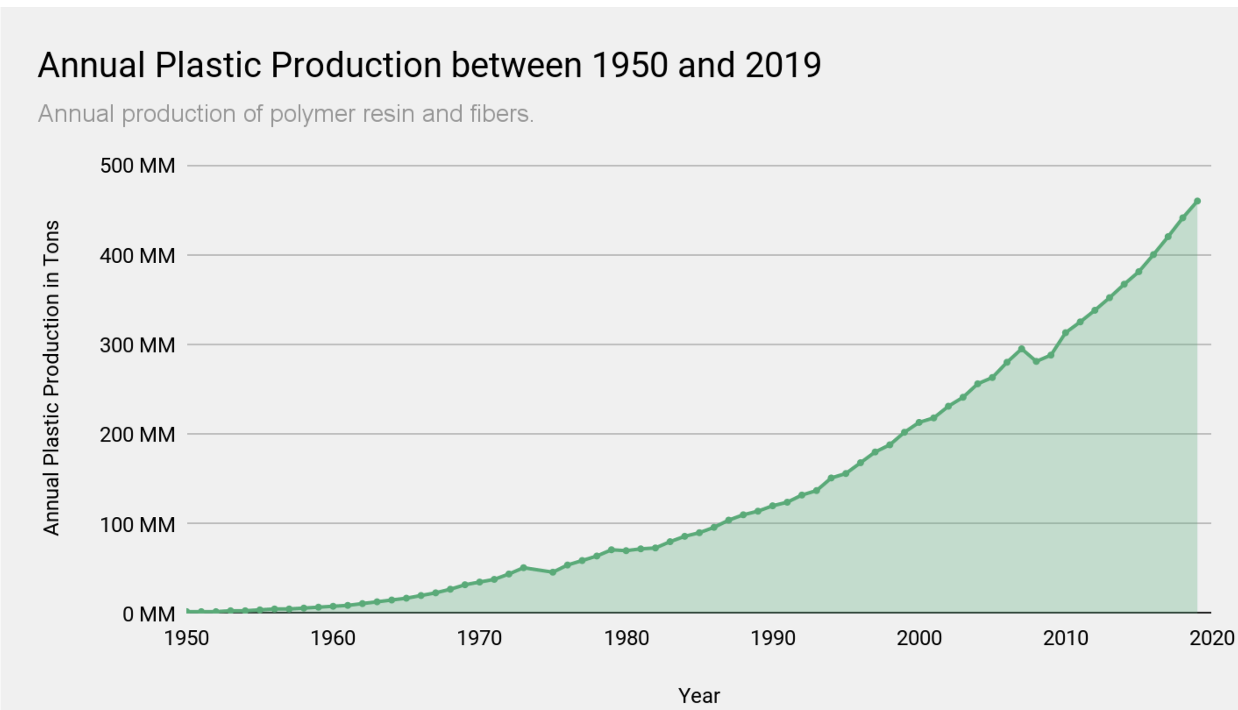

Figure 2. Total annual plastic production is global annual pure polymer (resin) production data from 1950 to 2019, published by the Plastics Europe Market Research Group, and global annual fiber production data from 1970 to 2019 published by The Fiber Year and Tecnon OrbiChem. *Sources: Geyer et al. (2017); OECD (2022)*

As plastic production and usage increased, so did the accumulation of plastic waste in the environment. Plastic waste has been found on beaches, shorelines, sea surfaces, the deep sea, and even arctic sea ice (Nelms et al., 2018; Law et al., 2010). This issue was first identified as a global concern in the 1980s, about 30 years after the start of mass plastic production (Pruter, 1987). Early reports included observations of small floating plastic particles, synthetic fibers in water samples, large floating debris, and plastic litter on beaches. However, it has only recently been recognized as a pervasive global issue.

FACTORS CONTRIBUTING TO THE PROBLEM

By focusing on the cause areas that are highlighted, KAB engages communities, foster sustainable behavioral changes, and create visible, impactful results (Figure 3). Moreover, these causes present opportunities for partnerships and the development of scalable models that can be replicated in other regions, maximizing KAB's reach and resources for broader environmental preservation maximizing KAB's reach and resources for broader environmental preservation efforts.

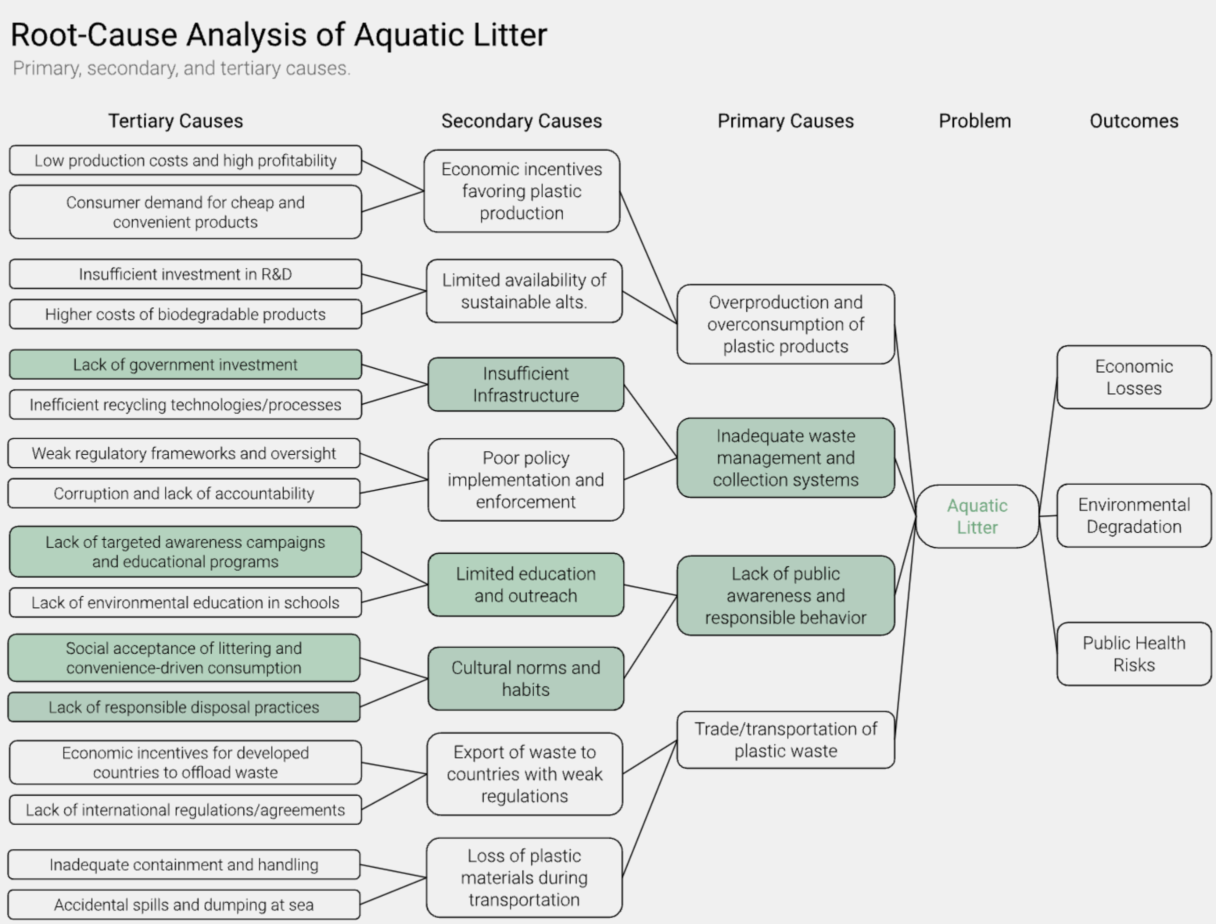

Figure 3. Root cause analysis of aquatic litter, identifying the relationships between primary, secondary, and tertiary causes leading to environmental, economic, and public health consequences. The diagram outlines the complexity of the issue, from production and consumption patterns to deficiencies in waste management and public education.

Inadequate waste management and collection systems are a large contributor to aquatic litter. In many regions, particularly rural areas, the absence of efficient waste management systems leads to dumping and burning of waste. This not only affects the land but also allows plastics to enter the waterways, adding to the aquatic litter problem. A proper waste management system is critical to prevent the flow of plastics into the ocean (Okunola et al., 2019; Vinti & Vaccari, 2022) The lack of adequate infrastructure for waste collection and management can lead to a significant increase in mismanaged plastic waste, a portion of which can end up in our oceans. For instance, many countries with dense coastal populations are a major source of oceanic plastic due to the absence of effective waste management systems. Similarly, predictions have shown that without proper intervention, the levels of mismanaged plastic waste generated within 50 km of coastlines will increase significantly, with a substantial percentage transforming into marine debris (Ng et al., 2023; Watt et al., 2021). A lack of government investment in waste management procedures and infrastructure exacerbates this problem. Therefore, KAB can intervene in this area, investing in waste management solutions (Simpson, 2012).

Additionally, without widespread public awareness and a sense of responsibility, plastics continue to enter the aquatic environment where they cause harm to wildlife and economic damage to marine-dependent industries. The economic impact of marine plastics, excluding microplastics, has been estimated to be about $13 billion per year, highlighting the severity of the issue (Gallo et al., 2018). Cultural acceptance of single-use plastics and convenience-based consumption patterns play a substantial role in the plastic crisis. These norms facilitate the proliferation of plastic litter by sustaining the demand for single-use, disposable products, thus increasing the volume of plastic waste generated and improperly managed. Moreover, the deficiency in public education regarding waste management and the environmental impacts of plastic pollution contribute to improper disposal practices. Studies from Southeast Asia and Nigeria illustrate the correlation between low plastic literacy and the high levels of unmanaged waste, which result in substantial environmental and economic repercussions (Phelan et al., 2020).

HISTORICAL BARRIERS TO ADDRESSING THE PROBLEM

There are strong economic incentives for producing plastic, which is often cheaper and more convenient than alternatives. The production and sale of plastic products are profitable ventures for businesses, and this drives overproduction and overconsumption, contributing to the accumulation of litter in waterways (EPA, 2024; Walker et al., 2020). Many communities also lack the necessary infrastructure for proper waste management. This includes not only physical infrastructure like trash bins and recycling centers but also the programs and systems needed to encourage and facilitate waste reduction, reuse, and recycling. Moreover, there is often a lack of strong policy frameworks and enforcement mechanisms to prevent littering and ensure proper waste management. Without effective regulations and consistent enforcement, there is little deterrence against littering and improper disposal of waste (EPA, 2024). This is in part due to often underfunded and understaffed municipalities. This shortfall can lead to inadequate cleanup efforts and prevent the implementation of long-term solutions.

The issue of litter is a transitive one, with waste often crossing borders through rivers and oceans. This complexity makes it difficult to tackle the problem at the source and requires interregional and interagency cooperation which is often challenging to achieve (EPA, 2024). Additionally, current recycling and waste management technologies may not be efficient or advanced enough to handle the volume and variety of waste being produced, particularly when it comes to plastics and microplastics. Finally, despite growing awareness, there is still a significant gap in public understanding of the severity of the issue and the actions needed to address it. Behavior change is slow, and littering continues to be a problem, often due to habit, lack of convenient disposal options, or ignorance of the environmental impact (EPA, 2024).

IMPACT ON CRITICAL SUB-POPULATIONS

Aquatic plastic pollution is increasingly recognized as not only an environmental issue but also a significant equity issue, disproportionately affecting marginalized communities such as Environmental Justice (EJ) communities, Black, Indigenous, and People of Color (BIPOC), and low-income groups. These communities often bear the brunt of the adverse effects of plastic pollution due to systemic inequities and historical marginalization.

Health impacts are a primary concern, as these communities are more likely to live near polluted waterways, exposing them to toxins leached from plastics (Fedinick et al., 2019). This exposure can lead to various health problems, including endocrine disruption, reproductive issues, and an increased risk of certain cancers. Furthermore, the accumulation of plastic litter can create breeding grounds for disease-carrying organisms, exacerbating the spread of waterborne diseases. These populations may also have limited access to healthcare and face other socio-economic barriers to maintaining good health, making them more vulnerable to the adverse health effects of aquatic plastic pollution (Fedinick et al., 2019; Johnston et al., 2019).

Economically, the presence of aquatic plastic pollution can have devastating effects on livelihoods, particularly in communities reliant on fishing and tourism. Fish stocks can be reduced, and fishing gear damaged due to plastic debris, directly impacting the income of fishermen, many of whom belong to low-income or BIPOC communities (Landrigan et al., 2020). Additionally, tourist spots plagued by litter lose their appeal, impacting local small businesses and economies dependent on tourism revenue.

The issue of aquatic plastic pollution also highlights broader themes of environmental injustice. EJ communities, BIPOC, and low-income groups often face a disproportionate burden of environmental degradation while having limited capacity to mitigate or adapt to these challenges. Addressing this issue requires a multifaceted approach that considers the social, economic, and cultural dimensions of environmental justice. Accordingly, efforts to mitigate aquatic plastic pollution should prioritize community involvement and empowerment, ensuring that the voices of those most affected are heard and considered in policy-making processes. By recognizing and addressing the disproportionate impacts on marginalized communities, decision makers can work towards more equitable and sustainable solutions to this pressing environmental challenge.

CONSEQUENCES

Aquatic litter has far-reaching impacts that extend beyond the confines of water bodies to affect ecosystems, economies, and public health. This section delves into the multifaceted consequences of aquatic litter, exploring its detrimental effects on marine and freshwater habitats, the economic costs associated with litter management and tourism decline, and the public health risks posed by pollution and associated toxins. By examining the environmental, economic, and public health impacts of aquatic litter, decision makers can better understand the urgency of addressing this global challenge and the need for comprehensive strategies to mitigate its effects.

ENVIRONMENTAL IMPACTS

The environmental impacts of aquatic litter are profound and far-reaching, affecting a wide range of aquatic environments including oceans, rivers, lakes, and wetlands. The pervasive presence of plastic and other debris in these ecosystems poses serious threats to marine and freshwater species, as well as to the overall health of aquatic habitats. From ingestion and entanglement to the alteration of habitat characteristics and the spread of invasive species, the consequences of aquatic litter are multifaceted and interconnected. In this context, it is crucial to understand the various ways in which aquatic litter impacts different species and ecosystems

Plastic ingestion is a common issue for marine organisms, as they often mistake small plastic items like bottle caps, balloons, and lighters for food. This ingestion can lead to severe health problems, including starvation due to the blockage of digestive tracts and internal injuries from sharp plastic edges. A study by Wilcox et al. (2015) estimated that 90% of seabirds had ingested plastic, highlighting the widespread nature of this problem. Moreover, entanglement in debris such as packing bands, rubber bands, six-pack rings, and mesh bags presents another significant threat. This can lead to restricted movement, drowning, starvation, and increased vulnerability to predators. According to a report by the National Oceanic and Atmospheric Administration, entanglement has affected a wide variety of species, including 44 sea bird species, nine cetacean species, 11 pinniped species, 31 invertebrate species/taxa, and six sea turtle species in the United States alone (NOAA, 2014). However, the impact of aquatic litter extends beyond individual animals to entire ecosystems. Coral reefs, which are vital marine habitats, are particularly vulnerable to plastic pollution. Litter can smother corals, block sunlight, and facilitate the spread of invasive species and pathogens. When corals are in contact with plastic the likelihood of disease increases from 4% to 89% (Lamb et al., 2018).

In riverine ecosystems, plastic debris also poses significant environmental challenges, as rivers act as major conduits for transporting plastic waste from inland areas to the ocean. The accumulation of plastic debris can alter the physical characteristics of river habitats, affecting the flow of water and the availability of light and oxygen for aquatic organisms (Wagner et al., 2014). This alteration can lead to decreased biodiversity as plastic debris entangles and harms a wide range of riverine species, including fish, birds, and invertebrates (Sanchez et al., 2014). Although freshwater bird species are thought to have a lower risk of harm than seabird species, experts estimate that around 10% of freshwater birds still face entanglement (Ryan, 2018). Additionally, the degradation of plastic debris can release various additives and by-products into the water, negatively affecting the chemical quality of river water (Lambert & Wagner, 2017). These microplastics also absorb and concentrate toxic chemicals from other sources (i.e. metals), which can then be ingested by aquatic organisms, potentially leading to bioaccumulation and biomagnification of harmful substances (Eerkes-Medrano et al., 2015). Plastic debris also acts as a vector for transporting invasive species and pathogens, disrupting local ecosystems and causing further ecological imbalances (Rech et al., 2016). These issues underscore the urgent need for efforts to reduce plastic production, improve waste management, and enhance public awareness to mitigate the adverse effects of aquatic litter on the environment.

ECONOMIC IMPACTS

The economic impacts of aquatic litter, particularly plastic pollution, are significant and far-reaching, affecting various sectors (Figure 4). Plastics, whether through leakage during production and use, or as direct littering, end up as waste in our environment, imposing significant economic costs. These costs are diverse, spanning from the direct expenses to subtler, yet considerable, economic repercussions such as losses to fisheries and aquaculture and a reduction in tourism.

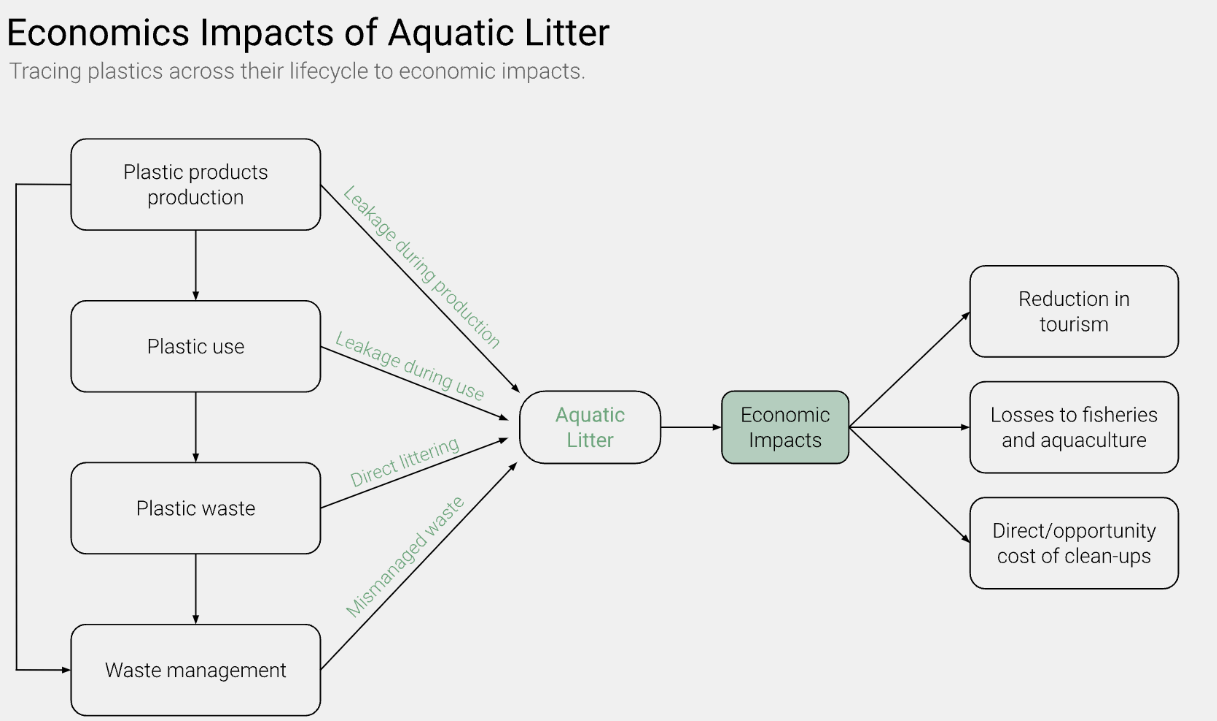

Figure 4. Plastics impact fisheries through dumped catch, fouling incidents, net repairs and time lost cleaning nets. Tourism can be impacted when tourists are no longer willing to visit, due to plastic litter on beaches. In order to avoid this impact, beach clean-up costs need to be incurred. These, and other factors, are costs associated with marine plastic pollution

While primarily discussed in the context of environmental degradation, aquatic litter also poses a tangible threat to the economic vitality of coastal regions through its impact on tourism. The recreational value of aquatic environments is deeply intertwined with their cleanliness and the visual aesthetic they offer. Studies have illustrated a direct correlation between the presence of aquatic litter and the frequency of beach visits, which in turn affects local economies (Adam, 2021; English et al., 2019).

In coastal Ohio, particularly along the shores of Lake Erie, beachgoers have shown a significant response to changes in marine debris levels. The potential for increased visits, estimated at 2.8 million additional visitor days with the elimination of debris, hints at a substantial opportunity for economic growth through tourism. The increase in visitor days leads to an additional 3,700 jobs related to tourism. This increased footfall could translate into an increase of $88 million in recreational value, or individuals' willingness to pay for recreational access to beaches, or for policies that improve beach recreation (English et al., 2019). This results in an increase in tourism spending by $217 million. This figure is a measure of the effect of beach recreation on spending by consumers and businesses in the region. It includes both direct spending on recreational activities and the effects of direct spending in stimulating the local economy (Gupta et al., 2023). Conversely, the scenario in Orange County, California serves as an example of the adverse economic effects that can result from an increase in marine debris. With an estimated decrease of 4.6 million visitor days due to a doubling in debris, the subsequent financial loss is profound. Researchers estimate that this would result in a decrease of $275 million in recreational value and decrease of $414 million in tourism spending. The cascading impact would be seen in diminished tourism expenditure within the community and a decline in job opportunities, calculated to be nearly 4,300 jobs (English et al., 2019).

Aquatic litter can also affect fish health, reduce populations, and damage fishing equipment, leading to economic losses for fishers and aquaculture operations. In fisheries, the presence of aquatic litter poses a hazard to fish stocks by contributing to habitat destruction and introducing toxic pollutants into the aquatic food web. These pollutants can accumulate in the tissues of fish, potentially rendering them unsafe for human consumption. According to the Food and Agriculture Organization of the United Nations (FAO), the contamination of fish with harmful debris can lead to the rejection of seafood batches by consumers and can impose significant health risks (FAO, 2016). Moreover, the financial implications of cleaning up litter from fishing areas are substantial. McIlgorm et al. (2011) estimated that the Asia-Pacific region's economic impact on the fishing industry due to aquatic litter might exceed $1.26 billion annually. While the financial repercussions may differ in scale across various regions, the United States, with its extensive coastlines and significant fishing industry, undoubtedly experiences a considerable economic burden as well. For example, in the Mississippi Sound, alone, Posadas et al. (2024) found that 17% of shrimp caught were lost due to marine debris encounters, resulting in foregone total sales and job impacts of $3.2 million and 33 jobs in shrimping and associated businesses. Further, the United Nations Environment Programme (UNEP) has highlighted the extensive costs associated with marine litter to the fishing industry, including the cost of removing litter from the beaches, which is often done by the fishers themselves, to protect their livelihoods (UNEP, 2016).

The cost to the aquaculture industry is similarly steep. Debris can entangle and damage aquaculture equipment, such as nets and cages, leading to costly repairs and loss of stock. Aquaculture facilities located near polluted coastlines can suffer losses from the decreased quality of their product and increased operational costs associated with litter management. Sustainably managed aquaculture is especially at risk, as the presence of litter can jeopardize certification status, essential for market access and premium pricing. In a study by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), it was estimated that the economic burden of marine debris on aquaculture in the Australian region could be in the millions of dollars (Harding, 2016).

There are also opportunity costs and direct costs associated with cleanup efforts. Opportunity costs relate to the benefits that communities forego when resources are allocated to cleaning up litter rather than to other community services or economic activities. These can include the diversion of public funds from infrastructure projects, educational programs, or healthcare services. Municipalities in the United States spend hundreds of millions of dollars annually on litter prevention, cleanup, and education. This expenditure represents a substantial opportunity cost as these funds could be allocated elsewhere to potentially yield higher social returns (Murphy et al., 2021; Kirkley & McConnell, 1997).

Direct costs of cleanup include the labor, equipment, and transportation needed to collect and properly dispose of or recycle litter. These costs can be considerable. Keep America Beautiful found that the U.S. spends an estimated $11.5 billion each year on cleaning up litter, with municipalities bearing the brunt of these expenses (Lisa, 2021). According to the Ocean Conservancy, the annual expenditure on coastal and marine litter cleanup can run into millions of dollars for individual states, with a considerable portion contributed by volunteer efforts (Ocean Conservancy, 2020). Moreover, Newman et al. (2015) point out that marine debris cleanup efforts are particularly costly due to the expansive areas to be covered and the difficulties in retrieving debris from aquatic environments.

PUBLIC HEALTH IMPACTS

Aquatic litter, especially plastic waste, has proliferated in oceans, rivers, and lakes worldwide. Its presence in aquatic environments has direct and indirect public health implications. This section outlines the current knowledge on the health impacts of aquatic litter and evaluates the economic burden on health systems.

Aquatic environments polluted with litter can pose physical risks to individuals engaging in recreational activities or occupational tasks. Sharp objects such as broken glass and metal can cause cuts or wounds that may lead to infections. For example, a study by Beeharry et al. (2017) noted that beachgoers frequently encounter and can be injured by litter such as syringes and sharp plastics, resulting in the need for medical intervention.

Plastics in the ocean disperse, breaking into smaller particles spreading pollution throughout the water column (Barry, 2021). These plastics absorb toxins from external sources before entering the ocean, leading to contamination of marine life. Marine litter, particularly plastic, can absorb and leach toxic chemicals, including polychlorinated biphenyls (PCBs) and heavy metals. These toxins can accumulate in marine organisms, eventually entering the human diet. Consequently, when humans consume these contaminated animals, they absorb the toxins. Various types of plastics pose dangers to human health, including direct toxicity from lead, cadmium, and mercury, which have been found in ocean fish. Diethylhexyl phthalate (DEHP), present in some plastics, is a toxic carcinogen, linked to cancer, birth defects, immune system problems, and developmental disorders in children (Munshi et al., 2013). Lastly, Bisphenol-A (BPA) and phthalates, used in products like plastic bottles and food packaging, break down over time and can enter the human body, disrupting hormonal function (Konieczna et al., 2015). Similarly, a review by Galloway (2015) highlighted the potential for such pollutants to cause hormonal imbalances, developmental disorders, and cancer when humans consume affected seafood.

Aquatic litter provides a habitat for microorganisms, including pathogens that can be harmful to humans. Waste materials can act as vectors for diseases such as cholera when they contaminate water supplies (Kwun Omang et al., 2021). These conditions are particularly concerning in areas with poor waste management systems, where litter is likely to come into contact with sources of drinking water.

The presence of litter in coastal and aquatic environments can have psychological effects on individuals and communities. Research by Sussarellu et al. (2016) has linked pollution to decreased quality of life and increased stress levels among residents of affected areas. Moreover, the aesthetic degradation of natural environments can diminish the sense of community ownership, leading to social disillusionment.

EVIDENCE ON EXISTING SOLUTIONS

Reviewing scientific literature from the past decades, this literature review summarizes key solutions now implemented in different contexts that could address plastic and microplastic contamination from source to sea at scale. These include general policy options (i.e. bans, extended producer responsibility, guidelines, standards and protocols) to reduce use, reuse, and recycle plastics and microplastics alongside options to manage plastics in-stream (i.e. booms, cleanup boats, trash racks, Seabins), and microplastics (i.e. stormwater, municipal wastewater and drinking water treatment). Managing water pollution from plastics requires an approach that: (1) Reduces plastic and microplastic pollution at source and, (2) treats the pollution when contamination of aquatic ecosystems has already occurred (McKinsey & Company & Ocean Conservancy, 2015; Rhodes, 2018). The review examines the efficacy, and upfront capital operational costs of technologies, policy implementation costs (where available), and suitability under various conditions. This guidance can help to inform sustainable and cost-efficient solutions to the plastic problem.

POLICY MEASURES

Managing plastic leakage is the first step in controlling plastic pollution, requiring robust policy backing (McKinsey & Company & Ocean Conservancy, 2015; Eriksen et al., 2018; Lau et al., 2020). Most countries have implemented policies on solid and liquid waste management. However, these may be incomplete, with gaps that don't support sustainable practices, and poorly enforced, seriously hindering areas in addressing plastic waste issues. Nevertheless, policy measures are vital to find solutions for plastic waste management and mitigation. Generally, a combination of solutions and strategies is required at different levels of the plastic management chain for sustainable intervention, including prevention and control strategies (EU, 2015; Nikiema et al., 2020; Shin et al., 2020). Preventative measures can improve resource efficiency and decrease waste through bans and restrictions. Control strategies help inform on-the-ground practices and better define stakeholder roles and responsibilities.

Bans to Reduce Plastic Use

So far, over 67 nations have embraced a variety of prohibitions on disposable plastics, including foamed plastic products like styrofoam and plastic packaging, along with plastic bags (UNEP, 2018). Recent research indicates that the enforcement of plastic bans achieved success, resulting in a 50-90% reduction in plastic usage during the initial year of implementation in 60% of cases (UNEP, 2018; Xanthos & Walker, 2017). In other instances, (i.e. India, South Africa, developing nations), the enforcement of bans faced obstacles such as insufficient awareness about the policy, weak institutional capacity, poor governance leading to limited policy enforcement, a lack of suitable and affordable alternatives to replace banned plastic-based products, or non-prohibitive levies (Gupta, 2011; McKinsey & Company & Ocean Conservancy 2015; Borrelle et al., 2020). Similarly, to combat wastewater contamination caused by microbeads, the Netherlands and the USA (Microbead-Free Water Act) were among the first to implement bans on microbeads in personal care and cosmetic products. They were subsequently followed by numerous other countries (Xanthos & Walker, 2017; Guerranti et al., 2019). These bans prompted major manufacturing companies to initiate efforts to phase out the use of microbeads (Prata 2018; Guerranti et al., 2019). As a result, microbeads are now being replaced by alternative abrasives such as perlite, silica, and microcrystalline cellulose (OECD, 2021).

In a study conducted by Marsden Jacob Associates (2016) found that the benefit-cost ratio was 1.28 for total plastic bans in relation to 1.01-1.07 for partial bans and voluntary bans (or some combination of the two). Although enforcing complete bans to mitigate pollution is expensive, it proves most beneficial. Bans have various effects on stakeholders, but by implementing a polluter-pays principle, governments can ensure that producers of plastic internalize the cost of managing plastic to prevent damage to human health and the environment (Prata,2018).

Extended Producer Responsibility

Extended Producer Responsibility (EPR) is a policy strategy that holds manufacturers legally and financially accountable for minimizing the environmental impacts of their products at all stages of their life cycle (Walls, 2006). This approach can have a significant impact on reducing the health, safety, environmental, and social consequences of plastic products, contributing to the prevention and mitigation of plastic pollution in aquatic ecosystems (Abbott & Sumaila, 2019; Eriksen et al., 2018; Harris et al., 2021). For instance, in California, the Natural Resources Defense Council introduced a policy in 2013 that required producers to not only handle recycling but also tackle litter prevention and reduction, mandating a 75% reduction in product volume in the environment within six years and a 95% reduction within 11 years (Eriksen et al., 2018).

Many countries are turning to EPR to improve plastic waste management, particularly for domestically produced plastic items like water bottles, where some notable successes have been achieved (Filho et al., 2019). However, enforcement, which demands the ability to monitor disposable products generated by each company, poses difficulties, especially in data-scarce developing countries (Ugorji & van der Ven, 2021).

Deposit Recovery Systems

Deposit Recovery Systems (DRS), also known as bottle bills, are effective policy instruments for enhancing recycling rates and reducing litter. DRS operates by charging consumers a small deposit for each purchased drink in a plastic or metal container, which is refunded upon the return of the empty container for recycling. This system not only encourages recycling but also reduces litter, leading to environmental and financial savings. Research conducted by the British government found that countries implementing DRS achieve collection rates between 80% and 95%, significantly improving recycling rates (House of Commons, 2017). Moreover, Hawaii reported a 60% reduction in beverage bottles found in its litter within three years of implementing a bottle bill (The Abell Foundation, 2012).

Despite widespread access to curbside recycling, the collection rate for beverage containers remains below 40% of the volume produced, indicating significant room for improvement (Reloop, 2021). The National Association of PET Container Resources (NAPCOR) recently claimed that recyclers collected 36.8% of PET beverage bottles produced for the U.S. market as of 2020 (NAPCOR, 2022). Modernizing DRS infrastructure in the Northeast could elevate recycling rates to between 65% and 92%, capturing 1.2 billion beverage containers that would otherwise end up in landfills, with an additional cost of only one cent per container across the entire system. In states like Maine, with comprehensive DRS programs, recycling rates for containers reach as high as 84% (Reloop, 2021)

Other Guidelines, Standards, and Protocols

The plastic waste management sector requires clear policies to guide the interventions and protocols for the practices it promotes (Fletcher et al., 2021). da Costa et al. (2020) examine the current regulatory standards globally, focusing on the existing proposals and the foreseen challenges that may restrain the relevancy and suitability of such legislative proposals. Preventive, mitigating, removing, and behavior-changing management schemes to address litter all play a crucial part in forming policy intervention (Chen, 2015).

Recently concern over microplastics in wastewater has grown, but its actual impacts are not clear (WHO, 2019). Accordingly, no country has established quality standards for microplastics in treated wastewater or in the context of drinking water treatment (Novotna et al., 2019). A significant challenge arises from the absence of standardized analytical techniques for the quantification of microplastics in water, further complicating efforts to assess the extent and consequences of the microplastics issue (Elkhatib & Oyanedel-Craver, 2020; OECD, 2021).

TECHNOLOGIES TO CONTROL MACROPLASTICS

Seabin Technology

Seabins, which are designed to be deployed in tranquil aquatic environments, serve as floating waste receptacles, effectively collecting floating debris and even plastic particles measuring as small as 2 mm on the surface of both freshwater and marine environments (Nikiema et al., 2020). These Seabins operate by drawing water in through their openings, with the water subsequently passing through an internal filter bag that selectively captures the waste (Riggs & Naito, 2012). Notably, both small and large Seabins have proven their effectiveness in locations such as California, Oregon, Hawaii, and Texas (Forbes et al., 2019).

Litter Boom Technology

A litter boom is a floating barricade of buffers that intercepts surface waste (including plastics) in aquatic ecosystems by leveraging currents. The logs are typically connected with steel fasteners (Nikiema et al., 2020; Schmaltz et al., 2020; Schwarz et al., 2019). Booms can work independently, but may also be used with cleanup boats or autonomous robots to collect trapped waste (Helinski et al., 2021). Cleanup boats gather waste from the water's surface using nets and baskets (Cordier & Uehara, 2019). Different water conditions like drainage volume and weather necessitate different boom types (Nikiema et al., 2020). However, booms don't address plastics below the surface. Booms come in various shapes and sizes and are made of materials like styrofoam, polyvinyl chloride, and HDPE. Overall, booms appear to be an adaptable and practical technology for river plastic cleanup. The cost of booms declines as length increases, but the material used also affects costs. A study from the EPA (1999) found that the upfront capital cost of litter booms was between $180,000 and $270,000 in 2023 USD. Cheap inflatable booms may degrade in the sun over time leading to higher maintenance costs due to replacement (Tramoy et al., 2019).

Trash Rack Technology

Trash racks represent a widely employed approach to prevent the entry of debris, including plastics, into aquatic ecosystems (Zayed et al., 2018; Nikiema et al., 2020). These structures feature bars strategically positioned to obstruct and channel litter into a designated containment area before it gets carried downstream (Schmaltz et al., 2020). The spacing between these bars is determined based on the minimum size of waste to be intercepted (Zayed et al., 2018). While trash racks are typically constructed from mild carbon steel, specific applications also utilize materials like wrought iron, alloy steel, and stainless steel. A significant challenge associated with trash racks relates to their poor structural longevity, which is a critical design consideration (Zayed et al., 2018; Nikiema et al., 2020). Typically, the accumulated debris is removed through manual or mechanical means, often involving raking. Generally trash racks cost \$100–\$4,000 depending on material. However, structures constructed with heavy rail or steel range from \$3,000–\$30,000 or more depending on the size and materials required.

The technologies discussed in this section incur substantial operation and maintenance expenses due to the necessity to clear and remove accumulated waste (Brouwer et al., 2023). In their cost calculations, Nikiema and Asiedu (2022) found that Seabins are the least expensive (USD 1.24–1.55 per kg of plastic), while trash racks are second most expensive (USD 4.87–8.46 per kg of plastic) and litter booms are the most expensive (USD 22.5–30.1 per kg of plastic).

TECHNOLOGIES TO CONTROL MICROPLASTICS

Retention Ponds and Wastewater Treatment

Microplastics have been found in stormwater in strong concentration (Cho et al., 2023). End-of-the-pipe stormwater treatment in artificial basins called retention ponds has effectively prevented 40%-60% of microplastics from entering waterways (Hafner, 2010). Retention ponds used for stormwater runoff treatment are usually the most cost-effective way to remove microplastics, but require land creating an opportunity cost (Nikiema et al. 2020).

Municipal wastewater is purified in various steps: primary treatment, secondary treatment (activated sludge), and tertiary treatment (biological aerated filter). Primary treatment removes the majority of microplastics from wastewater (Raju et al., 2018), including light microplastics (Murphy et al., 2016), and heavier microplastics (Talvitie et al., 2017). Microplastics removal performance during this treatment stage usually attains 42–82% (Nikiema et al., 2020). In general, between 86 and 99.8% of microplastic particles in raw wastewater are removed after secondary treatment (Nikiema et al. 2020).

Sewage Sludge Treatment

Sewage sludge, a byproduct of wastewater treatment, contains a mixture of solids and water, including microplastics. During the wastewater treatment process, a substantial portion of microplastics, typically 69-99%, is transferred from the liquid phase to the sludge fractions created at different treatment stages (Nikiema et al. 2020). The average size of microplastics in the sludge tends to be larger than that in the initial wastewater, indicating a concentration of larger microplastics in the sludge. The composition of the sludge also varies based on the treatment phase and the specific biological wastewater treatment processes employed.

Land application is the primary post-treatment method for the stabilized sludge; however, it results in the long-term increase of microplastics in soils. These microplastics can be transported back to the aquatic environment through runoff water or wind. An alternative solution is sludge incineration, but this approach eliminates the opportunity to enrich soil health with organic matter and nutrients found in the sludge (Sun et al., 2018; He et al., 2018). Cost of sludge management is part of wastewater treatment plant costs, so there are no additional costs.

By no means does this section provide a comprehensive record of technologies or policies aimed at reducing plastic pollution in water (see Appendix I for additional common technologies).

EVALUATIVE CRITERIA

The following section outlines the evaluative criteria that will be used to assess the policy alternatives aimed at reducing aquatic litter. These criteria include Effectiveness, Cost, Feasibility, and Equity. Each criterion is crucial in determining the overall success and sustainability of the proposed solutions. The effectiveness of the alternatives will be measured based on their ability to achieve significant reductions in aquatic litter. The cost assessment will examine the total financial investment required for the planning, implementation, and ongoing maintenance of the initiatives. Feasibility will evaluate the practicality of implementing the solutions, considering factors such as community support, resource availability, and infrastructure capability. Lastly, equity will assess whether the impacts, costs, and benefits of the initiatives are fairly distributed across different populations. Together, these criteria provide a comprehensive framework for evaluating the potential effectiveness and sustainability of the policy alternatives in addressing aquatic litter reduction.

CRITERIA I: EFFECTIVENESS

Effectiveness in total litter reduction refers to the ability of interventions and initiatives to achieve measurable and significant reductions in the amount of litter entering waterways. From a theoretical standpoint, measurement could be based on the volume or weight of litter removed, decreased pollution levels, or improvements in water quality. In practice, the most common and easily understandable unit of measurement is weight (Smith & Turrell, 2021). Effectiveness will be determined based on data and literature that tracks litter levels before, during, and after implementation of strategies. Because data is not widely available, a model that draws on analogs within the literature and a series of assumptions to estimate the effect of a certain intervention will be developed. Populations under consideration should include areas adjacent to water bodies, urban and suburban regions, and locations with historically high littering rates. Data for this criterion can be sourced from government agencies, environmental organizations, and research institutions, as well as community reports and clean-up event statistics.

CRITERIA II: COST

In the context of aquatic litter reduction, the cost criterion specifically examines the total financial investment required for the planning, implementation, and ongoing maintenance of programs aimed at mitigating litter pollution in water bodies. Operationalizing the cost criterion involves a detailed analysis of all direct expenses associated with the initiative. Direct costs include tangible and immediate expenditures related to the design and execution of anti-litter programs. This encompasses expenses such as funding for public awareness campaigns, community education initiatives, organizing clean-up events, and any technological solutions employed to monitor and manage litter in waterways.

Operationalizing the cost criterion requires a thorough breakdown of all relevant expenditures. This includes labor costs for personnel involved in program implementation and maintenance, material costs for infrastructure improvements and equipment, administrative costs, and any other outlays tied to the anti-litter initiatives. By focusing on the total cost of implementing and maintaining programs, decision makers can gain a clear understanding of the resources needed to execute effective aquatic litter reduction strategies. For this section, costs are measured only within the first year of implementation.

CRITERIA III: FEASIBILITY

The measurement of feasibility is operationalized through the following framework that serves as a comprehensive tool for assessing the potential success and impact of various environmental initiatives. This framework is structured around seven key dimensions, each addressing a critical aspect of feasibility, including financial resources, technical expertise, community engagement, regulatory compliance, scalability, partnerships, and long-term sustainability. The utilization of this framework is justified by its ability to provide a holistic analysis of each initiative, taking into account both internal factors, such as the organization's capabilities and resources, and external factors, such as stakeholder support and regulatory environments. By systematically evaluating each dimension, KAB can make informed decisions about which initiatives to pursue, prioritize, or modify, ensuring that their efforts are both effective and sustainable in addressing environmental challenges. This framework is adaptable to a wide range of policy alternatives, making it a valuable tool for strategic planning and decision-making within the organization. Each dimension is scored on a scale from one to five with a total of 35 possible points across all categories. Dimensions are described in further detail below:

- Funding and Financial Resources: This dimension assesses the availability and sustainability of financial resources required for the initiative. It considers sources of funding, such as grants, corporate sponsorships, government support, and the costs associated with implementation and maintenance. A score in this dimension reflects the initiative's financial viability.
- Technical Expertise and Infrastructure: This dimension evaluates the technical feasibility of the initiative, including the availability of proven technology, the need for technical expertise, and the adequacy of infrastructure for installation and maintenance. A high score indicates that the initiative is technically sound and feasible.
- Community Engagement and Social Impact: This dimension measures the initiative's potential for community engagement and its expected social impact. It considers the level of public acceptance, the involvement of local stakeholders, and the initiative's contribution to raising awareness and changing behaviors related to litter reduction. A high score reflects strong community support and positive social outcomes.

- Regulatory Compliance and Policy Alignment: This dimension assesses the initiative's alignment with existing regulations and policies. It considers the ease of obtaining necessary permits, compliance with environmental regulations, and the initiative's support for broader policy goals. A high score indicates that regulatory hurdles are manageable and that the initiative aligns well with policy objectives.
- Scalability and Replicability: This dimension evaluates the potential for scaling up the initiative and replicating it in different contexts. It considers factors such as the adaptability of the technology, the availability of resources for expansion, and the initiative's potential for broader impact. A high score suggests that the initiative can be effectively expanded or replicated.
- Partnerships and Collaborative Networks: This dimension assesses the strength and effectiveness of partnerships and collaborative networks. It considers the involvement of various stakeholders, including local governments, businesses, environmental agencies, and community organizations, in the initiative. A high score reflects strong collaboration and shared goals among partners.
- Long-term Sustainability and Impact: This dimension evaluates the initiative's potential for long-term sustainability and its lasting environmental impact. It considers the durability of the technology, ongoing maintenance needs, and the initiative's contribution to long-term environmental goals. A high score indicates that the initiative is likely to have a sustained positive impact on the environment.

CRITERIA IV: EQUITY

Equity in aquatic litter reduction initiatives focuses on ensuring fair and just distribution of both the burdens and benefits of these efforts across diverse populations. It involves evaluating whether the impacts, costs, and benefits disproportionately affect certain demographic groups or communities (Guglyuvatyy, 2010). The equity framework described below focuses on ensuring that policies are fair and just, particularly in their impact on marginalized communities. This approach is grounded in the principles of environmental justice, which seek to address the disproportionate environmental burdens faced by disadvantaged groups. Each category is measured on a scale of one to three with a total of 15 possible points. Categories include:

- Impact on Marginalized Communities: This aspect emphasizes the importance of assessing how policies affect marginalized communities, particularly in terms of providing benefits such as improved environmental conditions and job opportunities. Research has shown that marginalized communities often bear the brunt of environmental degradation and have limited access to economic opportunities. Therefore, policies that aim to improve conditions in these communities are crucial for promoting equity (Brulle & Pellow, 2006).
- Equitable Distribution of Benefits: This component stresses the need for policies to distribute benefits equitably across different communities, especially those historically affected by pollution. The concept of distributive justice underpins this approach, advocating for the fair

allocation of resources and benefits to ensure that all individuals and communities have equal opportunities to thrive (Schlosberg, 2007).

- Community Involvement and Empowerment: This dimension highlights the importance of involving and empowering community members in the implementation and decision-making processes of policies. Participatory approaches are essential for ensuring that the voices and needs of marginalized communities are heard and addressed, thereby promoting procedural justice (Walker, 2012).
- Accessibility and Inclusiveness: This component focuses on the accessibility of the policy's initiatives to diverse groups, taking into account language and cultural considerations. Inclusiveness is key to ensuring that policies are effective and responsive to the needs of all community members, regardless of their background (Holifield, 2013).
- Addressing Systemic Issues: This component emphasizes the need for policies to address systemic issues related to environmental justice and to avoid placing undue pressure on marginalized communities. This involves tackling the root causes of environmental and social inequities, such as historical discrimination and economic disparities (Pulido, 2000).

Data sources for equity assessments include demographic studies and literature related to equitable policymaking. By addressing equity concerns, decision makers can foster inclusive and sustainable solutions that benefit all members of the community, regardless of socio-economic status or other demographic factors.

POLICY ALTERNATIVES

COMMUNITY EDUCATION & AWARENESS

Keep America Beautiful (KAB) can combat aquatic litter by launching an education campaign centered on Extended Producer Responsibility (EPR) and Deposit Recovery Systems (DRS). The strategy focuses on raising community awareness and advocacy regarding these systems, proven to effectively reduce litter and promote recycling in various contexts (Mapotse & Mashiloane, 2017; Almosa et al., 2017). KAB will administer the campaign, collaborating with local environmental organizations, government agencies, and community groups. Environmental educators, waste management experts, and community leaders will design and deliver educational materials and events.

The campaign will entail developing and distributing educational resources such as brochures, pamphlets, posters, and online content elucidating the concepts of EPR and DRS. Furthermore, it will feature workshops, webinars, and public forums to engage community members, allowing them to learn, inquire, and share insights. Leveraging social and traditional media platforms will broaden outreach and amplify the campaign's message.

KAB should convene stakeholders from local environmental organizations, government agencies, and community groups to develop a comprehensive outreach strategy. This collaborative approach will ensure that the campaign is tailored to the specific needs and priorities of each community. In collaboration with subject matter experts, KAB will develop a range of educational materials. These materials will be designed to be accessible and engaging, utilizing clear language and visually appealing graphics to effectively convey key messages about EPR and DRS. As part of this campaign, KAB will organize a series of community engagement events, including workshops, seminars, and interactive demonstrations, to foster dialogue and awareness. These events will be held in accessible locations, allowing residents of all backgrounds to participate. Volunteers can assist with outreach.

Initial funding for campaign development and planning will be sourced through KAB's existing budget allocated for educational initiatives. This seed funding will be used to kickstart the project and secure additional support from external partners and sponsors. Corporate sponsorships will play a significant role in financing the campaign, with businesses in industries affected by product packaging and waste management systems being targeted for collaboration. These partnerships may involve financial contributions, in-kind donations, or joint marketing efforts to promote the campaign's message. Grants from government agencies such as the Environmental Protection Agency (EPA) like the—Environmental education (EE) grants—will provide critical funding for specific aspects of the campaign, such as educational workshops in schools and underserved communities (EPA, 2023; Young).

The campaign will proceed in phases, beginning with planning and development, followed by the rollout of educational initiatives. Timed in alignment with significant environmental awareness events like Earth Day, the campaign will maximize visibility and participation. Key tasks during the first phase include conducting research on EPR and Deposit Recovery Systems, identifying target audiences, and assessing the existing infrastructure for educational outreach. The development phase will focus on developing educational materials, designing workshops and events, and creating promotional content for the campaign. Finally, the implementation phase will include educational workshops, events, and outreach activities in communities. Ongoing evaluation and monitoring will take place to assess the effectiveness of educational efforts and community engagement activities (Taylor et al., 2007).

There are multiple evaluation and implementation challenges that KAB must keep in mind when designing the campaign. Rigorous monitoring and evaluation mechanisms are necessary to assess the campaign's impact on community awareness and behavioral change, so they must have a system in place. Moreover, engaging a diverse array of stakeholders, including businesses, policymakers, and residents, will be critical for garnering active participation and support.

Effectiveness Assessment

To measure the effectiveness of an education campaign about EPR and DRS on litter reduction, the theoretical model below examines two stages: (1) the effect of an education campaign about EPR and DRS on the combined likelihood of implementation of EPR and DRS and (2) the effect of the combined implementation of EPR and DRS on litter levels. Each stage includes additional covariates that are significant and assumed to be exogenous. In this analysis (across alternatives) the true functional form of each regression is not considered, but it is assumed that estimates for parameters from the literature were achieved through necessary regression transformations. The first stage is as follows:

$$(1) \quad \text{Policy Implementation} = {}_0 + {}_1 \times \text{Education Campaign} + {}_2 \times \text{PW} + {}_4 \times \text{IC} + {}_5 \times \text{EI} + \varepsilon$$

In the realm of policy implementation, education campaigns play a crucial role in facilitating the adoption of environmental policies such as Extended Producer Responsibility (EPR) and Deposit Recovery Systems (DRS). Studies indicate that public information campaigns can have a moderate yet significant effect on behavior change, which in turn influences policy implementation. For instance, Hornik and Yanovitzky (2003) found that public information campaigns can lead to a 9% increase in the likelihood of policy adoption, while Kotchen and Reiling (2000) demonstrated that environmental education programs can boost recycling rates, suggesting a potential 25% increase in the implementation of recycling-related policies. Taking these findings into account, it is estimated that an education campaign might increase EPR/DRS policy implementation by approximately 17%. For the purpose of the regression above, the model assumes a 5% baseline implementation rate (i.e. the rate at which EPR and DRS policies are enacted in the absence of other influence).

Political will, defined as the commitment of local government and policymakers to environmental issues can affect the implementation of EPR/DRS. Based on research by Posner et al. (2016), we might assume that a strong political will is associated with a 20% increase in the likelihood of policy adoption. The coefficient on this binary variable could be estimated as 0.2. Moreover, institutional capacity or the ability of local institutions to enforce and manage policies is crucial for their implementation. A study by Nzeadibe & Ajaero (2010) suggests that higher institutional capacity (IC) among governmental bodies is associated with a 15% increase in the likelihood of policy adoption. Accordingly, the parameter for this binary variable could be estimated as 0.15. The presence of economic incentives such as subsidies or tax breaks for companies that adopt EPR/DRS can encourage implementation. Research by Dikgang & Visser (2012) suggests that economic incentives can increase the likelihood of policy adoption by 15%. As such, the parameter for this binary variable could be estimated as 0.15.

Based on the model above with low political will, low institutional capacity, and lack of economic incentives, this initiative is associated with a 22% likelihood that EPR/DRS policy will be implemented. Conversely, assuming high political will, high institutional capacity, and presence of economic incentives, the initiative is associated with a 72% likelihood that EPR/DRS policy will be implemented. These estimates will be used to provide worst case and best case scenarios when considering the effect of implementation on litter level. This stage is estimated in the regression below:

$$(2) \quad \text{Litter Level} = \lambda_0 + \lambda_1 \times \text{Policy Implementation} + \lambda_2 \times \text{PD} + \lambda_3 \times \text{ES} + \lambda_4 \times \text{PI} + \lambda_5 \times \text{EA} + \varepsilon$$

First, the model above assumes a baseline reduction of 5% in litter due to general environmental efforts. In terms of the main explanatory variable, based on research from Ogunmakinde et al. (2019), the model assumes a 30% reduction in litter due to DRS; the impact of EPR is less direct but estimated to contribute 10% reduction through improved waste management practices. The coefficient on policy implementation is based on the assumed average impact of EPR and DRS on litter level, which is estimated to be 0.20.

Population density, the number of people per square mile, is included as a control variable, recognizing that higher population density can lead to more litter due to increased human activity. Based on a study by Cole et al. (2014), it is assumed that a 10% increase in population density is associated with a 5% increase in litter, leading to an estimated parameter for PD of 0.005. Economic status, measured by the median income level, is another factor considered, acknowledging that economic conditions such as income levels can influence littering behavior. A study by Schultz et al. (2011) suggests that a 10% increase in median household income is associated with a 3% decrease in litter, resulting in an estimated parameter for ES of -0.003. Public infrastructure plays a role in litter levels, as the availability and quality of public infrastructure such as waste bins and recycling facilities can impact littering behavior. Research by Huang et al. (2018) indicates that a 10% increase in a public infrastructure quality index is associated with a 7% decrease in litter, leading to an estimated parameter for PI of -0.007. Finally, environmental awareness is considered, recognizing that general environmental awareness in the community can influence littering behavior. A study by Ojedokun (2011) found that higher levels of environmental awareness are associated with lower levels of littering, suggesting that a 10% increase in environmental awareness scores might be associated with a 4% decrease in litter. This leads to an estimated parameter for EA of -0.004.

To understand the effect of this model, we will create a synthetic (baseline) city that has average characteristics across covariates and compare it to an estimated rural area and an urban area (Appendix B). Based on the estimate under the higher likelihood policy implementation scenario, in an urban area, implementation is associated with a 19.86% decrease in litter levels. In a rural area, implementation is associated with a 19.14% decrease in litter levels. Based on the lower likelihood policy implementation scenario, implementation is associated with a 9.86% decrease in litter levels in an urban area and a 9.14 % decrease in litter levels in a rural area. These decreases are compared to a baseline city which does not undergo policy implementation.

Cost Assessment

The implementation of the policy alternative for the Community Education and Awareness Campaign on Extended Producer Responsibility (EPR) and Deposit Recovery Systems (DRS) involves a range of costs across different categories, with an overall estimated cost ranging from $215,000 to $515,000.

Planning and development can cost from $45,000 to $120,000. This category encompasses the foundational stages of the campaign, including research and analysis, strategy development, and project management. The costs are aligned with industry standards for comprehensive planning, which involves hiring consultants, identifying target audiences, and managing the project effectively. According to a guide by the U.S. Small Business Administration, initial market research can cost anywhere from $20,000 to $30,000, and additional strategic planning can increase the total cost (U.S. Small Business Administration, n.d.). Furthermore, the Project Management Institute emphasizes the importance of investing in skilled project management personnel to ensure the success of such initiatives (Project Management Institute, 2021).

Educational material development represents $50,000 to $110,000 of the total cost. This category covers the creation, printing, and distribution of educational materials such as brochures, posters, and online content. The costs reflect the need for high-quality, engaging materials that effectively convey key messages about EPR and DRS. A report by the Content Marketing Institute indicates that content creation can account for a significant portion of marketing budgets, with design and production costs varying based on the complexity and volume of materials (Content Marketing Institute, 2020).

Workshops and events can cost anywhere from $50,000 to $110,000. This category includes expenses related to event planning, coordination, promotional activities, and participant engagement. Hosting workshops and events is crucial for fostering dialogue and awareness about EPR and DRS. The costs are consistent with the logistical and promotional requirements of organizing successful events, which can vary based on factors such as venue rental, advertising, and participant incentives. A study by Eventbrite highlights the diverse costs associated with event planning, including marketing and promotion, which can represent a significant portion of the budget (Eventbrite, 2019).

Community outreach costs anywhere from $55,000 to $130,000. This category encompasses costs related to outreach personnel, travel and logistics, and community engagement activities. Effective community outreach is essential for building strong relationships and ensuring active participation in the campaign. The costs reflect the need for dedicated staff, transportation, and engagement initiatives to reach diverse community members. According to a report by the Nonprofit Finance Fund, personnel costs are often the largest expense for community-based programs, underscoring the importance of investing in skilled outreach staff (Nonprofit Finance Fund, 2019).

Ongoing evaluation and monitoring accounts for $15,000 to $45,000 of the total cost. This category covers expenses related to data collection, analysis, and reporting to assess the effectiveness of the campaign. Continuous evaluation and monitoring are critical for measuring the impact of educational efforts and making data-driven improvements. The costs are in line with the need for robust data collection and analysis tools, as well as the preparation of comprehensive reports. A guide by the Centers for Disease Control and Prevention emphasizes the importance of allocating significant resources for evaluation to ensure the success of public health campaigns (Centers for Disease Control and Prevention, 2014).

Feasibility Assessment

The Community Education and Awareness Campaign on DRS and EPR demonstrates moderate feasibility, with robust funding strategies, technical expertise, community engagement, and regulatory compliance. Keep America Beautiful (KAB) leverages its experience in developing educational materials, managing digital platforms, and engaging communities to create a campaign that aligns with environmental policies and promotes litter reduction and recycling. While scalability and long-term sustainability present some challenges, KAB's history of successful partnerships and a phased campaign approach offer a solid foundation for addressing these issues. Overall, the campaign scores 26 out of 35 in feasibility, indicating a well-conceived initiative, but with potential barriers to significant impact.

Funding and Financial Resources (4): The campaign's funding strategy is robust, combining KAB's existing budget, corporate sponsorships, and government grants. This mixed funding approach is feasible and has been successfully utilized in similar campaigns. Utilizing volunteers for outreach is a cost-effective strategy that KAB has experience in managing (Young, 2010; Brudney & Kellough, 2000).

Technical Expertise and Infrastructure (4): KAB's experience in developing educational materials and managing digital platforms suggests that the infrastructure for creating and distributing resources and organizing events is in place. The reliance on digital platforms and accessible community locations for events is feasible given the increasing use of online tools for education (Monroe et al., 2019).

Community Engagement and Social Impact (4): KAB has a history of engaging communities in environmental initiatives, suggesting a strong capacity for local participation. Engaging stakeholders early in the planning process can enhance community support. The campaign's focus on collaboration with local environmental organizations, government agencies, and businesses aligns with successful models of stakeholder engagement in environmental campaigns (Hartley, 2004; Reed, 2008).

Regulatory Compliance and Policy Alignment (4): The campaign aligns with environmental policies and regulations that promote litter reduction and recycling. Educating the public about EPR and DRS supports compliance with existing waste management regulations and encourages the adoption of more stringent policies.

Scalability and Replicability (3): The campaign can be adapted to different communities and regions. However, the success of scaling up depends on the availability of resources and the ability to tailor the message to diverse audiences. Expanding the campaign to a broader audience may require additional funding and partnerships.

Partnerships and Collaborative Networks (4): KAB's history of partnership-building positions the campaign well for cooperation among diverse stakeholders, which is critical for the campaign's success. Collaborating with local environmental organizations, government agencies, and businesses can enhance the reach and impact of the campaign (Selsky & Parker, 2005).

Long-term Sustainability and Impact (3): The campaign's phased approach, from planning to rollout and evaluation, aligns with best practices in campaign management. Timing the campaign with events like Earth Day can enhance visibility and participation. However, the complexity of EPR and DRS concepts may require innovative educational approaches to ensure long-term understanding and engagement (Andreasen, 1995; Earth Day Network, n.d.; Schwartz, 2012).

Equity Assessment

This initiative received an overall score of 10 out of 15 based on its strengths in addressing the disproportionate impact of pollution on marginalized communities, its inclusive approach to community involvement, and its efforts to ensure accessibility and inclusiveness. However, concerns were raised about its potential to reinforce existing inequalities and its reliance on corporate sponsorships, which could compromise its independence and effectiveness in addressing systemic issues.

Impact on Marginalized Communities (2): The campaign aims to raise awareness and advocate for systems that have been proven to reduce litter and promote recycling. This has an inherent equity dimension, as environmental pollution disproportionately affects marginalized and low-income communities. By targeting these issues, the campaign can contribute to environmental justice, ensuring that all community members benefit from cleaner and healthier environments (Schlosberg, 2007).

Equitable Distribution of Benefits (2): By focusing on raising awareness and advocating for systems that reduce litter and promote recycling, the campaign can directly benefit marginalized and low-income communities that are disproportionately affected by environmental pollution. This policy is designed to include marginalized communities into the fold with its inclusive programming and should lead to a relatively equitable distribution of benefits.

Community Involvement and Empowerment (2): Moreover, the campaign's phased approach, including planning, development, and rollout, is designed to actively involve community members in each stage. This participatory approach can enhance the sense of ownership and empowerment among residents, particularly in underserved communities, and ensure that their voices are heard in shaping the campaign (Arnstein, 1969).

Accessibility and Inclusiveness (3): The development of educational materials and events that consider language barriers, cultural relevance, and the varying levels of environmental literacy among different community groups addresses this concern. Ensuring that materials are available in multiple languages and that events are held in accessible locations can help bridge these gaps (Bullard, 1990).

Addressing Systemic Issues (1): One concern is the potential for reinforcing existing inequalities in environmental burden and responsibility. If the campaign primarily targets individual behavior change without addressing systemic issues and the role of industry in waste production, it may place undue pressure on marginalized communities to solve problems they did not create (Agyeman, Bullard, & Evans, 2003; Schlosberg, 2007). Additionally, the reliance on corporate sponsorships and partnerships with businesses in industries affected by product packaging and waste management systems could raise concerns about the campaign's independence and the prioritization of corporate interests over community needs. This could lead to a lack of trust in the campaign and skepticism about its motives, particularly in communities that have experienced environmental injustices (Gupta & Lebel, 2010; Walker, 2009).

SHIFTING SOCIAL NORMS

This policy alternative aims to reduce aquatic litter through collaborative efforts between Keep America Beautiful, public-private partnerships, and local communities. By organizing regular waterway and coastal cleanups, the initiative seeks to shift social norms regarding littering, ultimately decreasing littering behavior and promoting proper waste disposal practices. If areas are already clean, people are more likely to keep them that way (Chaudhary et al., 2021; Schultz & Mertens, 2023). In a multi-city study, Schultz et al. (2011) found that cleaning up existing debris in an area cut new cigarette butt litter by nearly half.

KAB will lead the initiative, providing its expertise in organizing community cleanups, mobilizing volunteers, and raising awareness about the importance of proper waste disposal. Participating cities will collaborate with KAB to identify priority areas for cleanups, allocate resources, and engage local communities in the initiative. KAB and partner cities will organize recurring cleanups of waterways and coastal areas. These cleanups will involve the removal of litter, including plastic debris, cigarette butts, and other waste, from shorelines, riverbanks, and other aquatic habitats. In addition to cleanups, the initiative will include educational tents at cleanup events to raise awareness about the impacts of litter on the environment and promote responsible waste disposal practices. The effectiveness of the initiative will be assessed through monitoring litter levels before and after cleanups and tracking community engagement and behavior change over time (i.e. surveys on littering habits, etc.).

In terms of planning and coordination, KAB should collaborate with local partners to conduct comprehensive assessments of waterways, beaches, and coastal areas across the nation to identify priority sites for clean-up. Assessment criteria include litter density, environmental sensitivity, and accessibility for volunteers. Utilizing diverse outreach channels such as social media, community newsletters, and local events, KAB can recruit volunteers from a wide range of demographics (Jorgensen et al., 2020). At the beginning of events, they should provide comprehensive training sessions for volunteers, covering safety protocols, proper handling of waste, and the importance of their contribution to environmental conservation. Additionally, they should equip volunteers with necessary tools and supplies, including gloves, bags, trash pickers, and first aid kits, to ensure their safety and effectiveness during clean-up activities.

When conducting cleanups, KAB should implement systematic cleaning strategies, such as dividing areas into sections and assigning teams to specific zones to maximize coverage and efficiency. They should also be sure to employ appropriate waste management practices, including segregation of recyclable and non-recyclable materials, and coordinating with local waste management authorities for proper disposal. To ensure the effectiveness and progress of clean-up efforts over time, monitoring mechanisms must be established, employing standardized metrics such as litter weight collected, area coverage, and community feedback. These metrics serve as indicators of the impact of each event.

Cleanups will be conducted regularly throughout the year, with the frequency and timing determined based on factors such as weather conditions, volunteer availability, and seasonal patterns of litter accumulation. They will target specific waterways, coastal areas, and shorelines that are known to be heavily littered or environmentally sensitive. Priority will be given to areas with high public visibility and ecological significance (urban waterfronts, popular recreational beaches, and estuarine habitats). Collaborating with local environmental agencies, community organizations, and citizen scientists, KAB should identify specific litter hotspots based on historical data, observational surveys, and stakeholder input, and may utilize geographic information systems (GIS) technology to map out these hotspots and prioritize areas for clean-up activities (Valiente et al., 2020).

As with other alternatives, evaluation and implementation challenges are important to consider. It is difficult to measure impact due to lack of reliable baseline data. Additionally, behavioral change takes time, making short term assessment of this factor challenging. The sustainability of volunteer involvement may also require incentives and support. Finally, small plastics and cigarette butts may still be present on beaches following cleanups (Loizidou et al., 2018).

Effectiveness Assessment

To measure the effectiveness of the Shifting Social Norms initiative on litter levels, a regression model estimates the effect of cleanups on litter levels. The regression model described below aims to explain variations in litter levels in a given area over time. The main variable of interest is Cleanup, a binary variable to indicate implementation of events that are expected to reduce litter levels. Based on Schultz et al. (2011), we can estimate that a cleanup event reduces litter levels by approximately 20% based on the mean of the range found in their research.

$$(3)\quad \text{Litter Level} = \mu_0 + \mu_1 \times \text{Cleanup} + \mu_2 \times PA + \mu_3 \times VE + \mu_4 \times U + \mu_5 \times TA + \varepsilon$$

Public awareness campaigns are designed to educate the public about the environmental impacts of littering and the importance of proper waste disposal. Increased public awareness can lead to behavioral changes that reduce littering rates. This control is important because it captures the potential indirect effects of general awareness efforts on litter levels over time. Drawing from the literature on environmental education campaigns, we can estimate a 2% median reduction in litter levels per 10% increase in public awareness efforts (Kollmuss & Agyeman, 2002). Thus, the parameter on PA can be estimated as -0.002. Additionally, volunteer engagement measures the level of community involvement in litter reduction efforts. High volunteer engagement can amplify the effects of cleanups and awareness campaigns, leading to more substantial litter reduction. This control is crucial because it reflects the community's commitment to maintaining clean environments. Assuming a 10% increase in volunteer engagement leads to a modest 1 to 2% reduction in litter levels, the coefficient on could be estimated to be -0.0015. Urbanization is associated with increased waste generation, consumption patterns, and population density, all of which can contribute to higher litter levels. Controlling for urbanization is important because it helps isolate the effects of the intervention from the underlying litter-generating dynamics of urban areas. Assuming a 10% increase in urbanization leads to a 3% increase in litter levels, this parameter could be estimated to be within the range of 0.003 (Hidalgo-Ruz

& Thiel, 2013). Finally tourism activity can lead to temporary spikes in litter levels due to increased foot traffic and consumption in tourist areas. Controlling for tourism activity is important because it accounts for the variability in litter levels that might be attributed to seasonal increases in visitor numbers. Based on Tudor & Williams (2006) findings, we can assume a 10% increase in tourism activity leads to a 1-3% increase in litter levels, meaning the coefficient on this covariate could be estimated to be 0.002.

Similarly to the previous policy alternative the effectiveness will be assessed in both urban and rural areas. Based on the calculations in Appendix II, in an urban area, this initiative is associated with a 24.87% decrease in litter levels; conversely, in rural areas, the initiative is associated with a 25.02% decrease in litter levels (again compared to a baseline city with no intervention.

Cost Assessment

This initiative requires a multifaceted investment to effectively reduce aquatic litter through clean-up events. The total cost of the policy is estimated to range from $110,000 to $290,000, with the largest portion of the budget allocated to planning and coordination, and cleanup events.

Planning and coordination costs range from $35,000 to $95,000: This category covers the costs associated with site assessments, project management, and partnership development. The costs are justified by the need for comprehensive environmental assessments to identify priority sites for clean-up, effective management of the initiative, and establishing collaborations with local partners and stakeholders. According to a report by the Environmental Protection Agency (EPA), environmental site assessments can vary in cost depending on the complexity and size of the area being evaluated (EPA, 2018). Additionally, project management costs are consistent with industry standards for managing large-scale environmental initiatives (Project Management Institute, 2021).

Volunteer recruitment and training can cost from $15,000 to $40,000. This category includes expenses related to outreach and recruitment of volunteers, as well as organizing training sessions on safety protocols, waste handling, and environmental conservation. A study by the Corporation for National and Community Service highlights the value of investing in volunteer recruitment and training to ensure the success of community-based initiatives (Corporation for National and Community Service, 2020).

Costs within the cleanup event category account for $35,000 - $85,000 of total costs. This category covers the costs of supplies and equipment for volunteers, as well as logistics and coordination of cleanup events. The expenses are justified by the need for proper tools and resources to ensure the safety and effectiveness of volunteers during clean-up activities, as well as the logistical requirements for organizing and coordinating large-scale events. According to a report by Keep America Beautiful, the average cost of a cleanup event can vary based on the number of participants and the scope of the cleanup (Keep America Beautiful, 2019).

Educational tents and materials cost between $10,000 and $25,000. This category includes costs for setting up educational tents and producing informational materials for awareness-raising. A study by the National Environmental Education Foundation emphasizes the effectiveness of educational materials in raising environmental awareness (National Environmental Education Foundation, 2017).

Monitoring and evaluation costs total $15,000 to $45,000. This category covers expenses related to data collection and analysis, as well as reporting on the impact of cleanups. The costs are consistent with the need for rigorous monitoring and evaluation mechanisms to assess the effectiveness of the initiative and make data-driven improvements.

Feasibility Assessment

The Shifting Social Norms initiative demonstrates strong feasibility, with an emphasis on community engagement, technical expertise, and collaborative partnerships. KAB utilizes its experience in volunteer mobilization and environmental conservation to coordinate effective cleanups, focusing on litter hotspots and fostering a sense of community responsibility. The initiative is well-aligned with environmental policies and regulations, ensuring compliance with waste management standards. While challenges exist in achieving long-term behavioral change and maintaining volunteer involvement, the initiative's comprehensive approach and KAB's successful track record in partnership-building provide a solid foundation for addressing these issues. Overall, the initiative scores 30 out of 35 in feasibility, indicating a well-conceived, sustainable, and potentially impactful program.

Funding and Financial Resources (4): The initiative requires funding for cleanup supplies, volunteer training, and waste management. Partnerships with local businesses and government agencies can provide financial and in-kind support, making this aspect feasible (Nigbur et al., 2010).

Technical Expertise and Infrastructure (4): Recruiting and training volunteers are crucial for the success of the cleanups, and KAB's experience in mobilizing volunteers can support this aspect. The use of GIS technology to identify litter hotspots can facilitate targeted cleanups, enhancing the initiative's efficiency (Bruyere & Rappe, 2007; Khan & Chatterjee, 2021).

Community Engagement and Social Impact (5): The initiative's focus on community cleanups and public-private partnerships aligns with successful models of community engagement in environmental conservation. Involving local communities and volunteers in cleanups can foster a sense of ownership and responsibility toward local waterways (Dono et al., 2010).

Regulatory Compliance and Policy Alignment (4): Coordinating with local waste management authorities for proper disposal of collected litter is essential and adds complexity, but it ensures compliance with waste management regulations.

Scalability and Replicability (5): Comprehensive assessments of waterways and beaches to identify priority sites for cleanups are feasible with KAB's expertise and collaboration with local partners.

Regular cleanups throughout the year can be planned based on weather conditions and volunteer availability, allowing for scalability (Nigbur et al., 2010).

Partnerships and Collaborative Networks (5): The initiative's collaborative approach involving KAB, local governments, environmental agencies, and community organizations is crucial for its success. Shared goals and responsibilities can enhance cooperation among these entities. KAB's Cigarette Litter Prevention Program and Great American Cleanup program are examples of successful partnerships (Schultz et al., 2013; Keep America Beautiful, 2019, 2020).

Long-term Sustainability and Impact (3): Achieving long-term behavioral change regarding littering habits may be challenging and requires sustained education and engagement efforts. Maintaining volunteer involvement over time may require incentives and ongoing support. Smaller items may remain on beaches after cleanups, necessitating targeted strategies for their removal (Dono et al., 2010; Bruyere & Rappe, 2007; Rathinamoorthy & Balasaraswathi, 2021).

Equity Assessment

This initiative scored a 13 out of 15 for its impact on marginalized communities, equitable distribution of benefits, and community involvement and empowerment, recognizing its potential to address environmental justice and engage all community members in environmental stewardship. However, it received lower scores for accessibility and inclusiveness and addressing systemic issues, indicating room for improvement in ensuring equitable access to resources and that the campaign addresses broader systemic factors contributing to environmental pollution.

Impact on Marginalized Communities (3): This policy measures high in terms of equity. The reduction of waterway litter has direct equity implications. Clean waterways and coastal areas are public goods that benefit the entire community. However, marginalized and low-income communities often bear the brunt of environmental pollution and have limited access to clean natural resources. By reducing litter, the initiative can contribute to environmental justice, ensuring that these communities enjoy the same environmental benefits as more affluent ones (Schlosberg, 2007; Agyeman, Bullard, & Evans, 2003). Additionally, this policy actively reduces trash which is crucial when considering that marginalized groups are more likely to face environmental hazards (Calderon et al., 1993).

Equitable Distribution of Benefits (3): This policy aims to clean up heavily littered areas with an understanding that historically marginalized, low-income communities often report more trash in their area (Jones, 2022). Because this policy prioritizes identifying urgent areas for cleanup it will have immediate benefits for these communities.

Community Involvement and Empowerment (3): This policy leads to increased community engagement and awareness about proper waste disposal practices. This outcome has an equity dimension, as it involves empowering all community members, regardless of their socio-economic status, to participate in environmental stewardship. The initiative's focus on education and changing social norms can help bridge knowledge gaps and foster a sense of collective responsibility for the environment (Cialdini, 2003; Kollmuss & Agyeman, 2002).

Accessibility and Inclusiveness (2): The equity of the outcomes of this policy depends on the inclusiveness of the initiative's implementation. For example, if the cleanups and educational activities are not accessible to marginalized groups or if the messaging does not resonate with diverse audiences, the benefits of the initiative may not be equitably distributed (Bullard, 1990; Mohai, Pellow, & Roberts, 2009).

Addressing Systemic Issues (2): By targeting priority sites based on comprehensive assessments and employing systematic cleaning strategies, the initiative ensures that efforts are focused where they can have the most significant impact. Educational tents at cleanup events raise awareness about the environmental impacts of litter and the importance of proper waste disposal, contributing to a cultural shift toward environmental stewardship. However, if the campaign primarily targets individual behavior change without addressing systemic issues and the role of industry in waste production, it may place undue pressure on marginalized communities to solve problems they did not create (Agyeman, Bullard, & Evans, 2003; Schlosberg, 2007).

AQUATIC LITTER CAPTURE TECHNOLOGIES

The implementation of Seabins and litter booms aims to address the pressing issue of plastic pollution in waterways. Seabins are floating trash bins equipped with a pump that continuously draws water into the bin, trapping floating debris (including plastics, oils, and other pollutants, from the surface of the water) while allowing water to pass through. The collected waste is then disposed of responsibly. A litter boom is a floating barrier designed to tactically prevent litter from continuing to float downstream. By strategically placing Seabins and litter booms in key locations, KAB can mitigate the harmful effects of waterway litter on aquatic ecosystems and wildlife while also raising public awareness about the importance of marine conservation (Hicks, 2018).

A litter boom should be used in contexts where there is a high concentration of floating debris in larger water bodies, such as rivers, lakes, or near the outlets of stormwater drains. They are particularly effective in areas with strong currents or where debris tends to accumulate due to natural water flow patterns. Litter booms can capture a wide range of debris sizes, making them suitable for locations with diverse types of litter. On the other hand, a Seabin should be used in more contained or calmer water environments, such as marinas, harbors, or sheltered coastal areas. Seabins are designed to capture smaller, floating debris and are ideal for locations where there is a need for continuous, low-maintenance litter collection. They are particularly effective in areas with a high level of human activity, where small litter items like plastic bottles, cigarette butts, and microplastics are prevalent.

KAB will spearhead the initiative, coordinating with local authorities, businesses, and community organizations to identify suitable locations for deployment and oversee installation and maintenance. Municipalities will play a crucial role in providing support and resources for the placement of technologies in their respective jurisdictions. Corporate sponsors and businesses operating along waterways will also be encouraged to sponsor and participate in efforts. Lastly, engaging volunteers in regular cleanup activities and monitoring the performance of Seabins will be essential for success.

The primary action for this alternative involves the deployment of Seabins and litter booms in key locations. These locations are likely to be chosen based on several factors, including high levels of waterway pollution, proximity to urban/rural areas, and ecological sensitivity. Placing Seabins and litter booms strategically ensures maximum effectiveness in capturing floating debris before it can further degrade the environment. Successful implementation of this policy requires collaboration among various stakeholders, including government agencies, non-profit organizations, local communities, and businesses. Partnerships may involve securing funding for the purchase, installation, and monitoring. Raising public awareness about the impact of plastic pollution on aquatic ecosystems and Seabins' and litter booms' roles in addressing can make the impact of this alternative twofold.

In implementing this alternative, KAB should conduct—engaging with local authorities, environmental agencies, and community stakeholders to identify suitable locations for Seabin and litter boom placement—a comprehensive assessment of potential deployment sites based on criteria such as litter hotspots, proximity to high-traffic waterways, accessibility, and environmental sensitivity (Parker-Jurd et al., 2022). GIS mapping and data analysis tools can be utilized to prioritize deployment sites and optimize coverage. Collaborating with manufacturers, corporate sponsors, and grant providers to procure the necessary equipment for deployment will be necessary. KAB will also have to coordinate logistics for transportation, anchoring, and connectivity to power sources, while ensuring compliance with regulatory requirements and obtaining permits for installation in waterways (Sahoo et al., 2021; de Vries, 2021). Implementing regular inspections and data collection protocols to evaluate Seabin and litter boom effectiveness, identify maintenance needs, and address any operational challenges will ensure sustainability in the long term.

The pilot program, lasting 6-12 months, will initiate with the deployment of ten Seabins in high-traffic waterway locations and one litter boom. These sites will be selected collaboratively with local authorities, environmental agencies, and community stakeholders. The pilot phase aims to assess the effectiveness of Seabins and litter booms in capturing floating debris and engage the local community in cleanup efforts. Activities include site selection, procurement, installation, and initial monitoring. Regular monitoring and feedback collection will be conducted to evaluate performance and gather stakeholder input. Following the pilot, a 1-2 month evaluation period will analyze data and stakeholder feedback to adjust deployment strategies and operational procedures. This process will inform the scaling up of the program for subsequent phases.

Effectiveness Assessment

The regression model described below aims to explain variations in litter levels in a given area over time. The main variables of interest are Seabin and Litter Boom, binary variables to indicate implementation of either technology. To measure the effectiveness of the waterway litter technologies initiative, the regression model can be specified as follows:

$$(4)\quad \text{Litter Level} = \gamma_0 + \gamma_1 \times \text{Seabin} + \gamma_2 \times \text{Litter Boom} + \gamma_3 \times \text{PD} + \gamma_4 \times \text{PI} + \gamma_5 \times \text{EA} + \varepsilon$$

Based on research from Nikiema & Asiedu (2022) we assume that Seabins and litter booms reduce litter by 20% and 15%, respectively, within the contexts where they are commonly implemented. The same coefficient estimates are used from the regression measuring the effect of policy implementation on litter levels in the first alternative section.

As previously mentioned, the design of Seabins enables them to operate continuously, which makes them particularly suitable for areas with heavy pedestrian traffic and dense populations where the accumulation of litter is a major issue. Conversely, litter booms are primarily used in rural settings, where they are placed across rivers, streams, or inlets to intercept floating debris. In the analysis, the main explanatory variable that is not relevant to the specific area under study is zeroed, ensuring that only the impact of the implemented technology is estimated. The results of this analysis indicate that urban implementation of Seabins is associated with a 25.35% decrease in litter levels, while the implementation of litter booms in rural areas is associated with a 19.67% decrease in litter levels, compared to a baseline city with no intervention.

Cost Assessment

Implementing Seabin and litter boom technologies necessitates a substantial investment to effectively tackle aquatic litter. The total cost for the whole pilot program is $291,000 to $552,000. The estimated cost for deploying Seabins ranges from $150,000 to $270,000, while the implementation of a litter boom technology is projected to cost between $141,000 and $282,000. A significant portion of the budget is allocated to planning and coordination, which is essential for the successful execution of these technologies. Both initiatives require comprehensive environmental assessments, stakeholder engagement, and effective project management to ensure their effective implementation. Additionally, the procurement and installation of the technologies represent substantial expenses.

Seabins: $150,000 to $270,000

Planning and coordination costs for Seabin Technology range from $30,000 to $60,000. These costs cover site assessments to identify suitable locations for Seabin deployment, project management to oversee the initiative, and stakeholder engagement to collaborate with local authorities, businesses, and community organizations. The need for comprehensive environmental assessments and effective management justifies these costs, as they ensure the successful implementation of the technology (Environmental Protection Agency, 2018; Project Management Institute, 2021).

The procurement and installation of Seabins account for $7,000 to $11,000 per unit. This policy calls for the procurement of ten Seabins. Costs include the purchase of the Seabin itself, installation costs for anchoring and connecting to power sources, and transportation and logistics for getting the units to their designated locations. The costs are influenced by the technology's design and the logistical challenges of installing equipment (Seabin Project, 2021). Maintenance and monitoring expenses are estimated at $15,000 to $30,000. Regular inspections are necessary to ensure the Seabins are functioning correctly, while data collection and analysis help evaluate their effectiveness in capturing litter. These activities are crucial for the long-term success of the initiative (Seabin Project, 2021).

The pilot program and evaluation phase can cost between $35,000 and $70,000. This phase includes the initial deployment of Seabins, community engagement, production of educational materials, and a thorough evaluation of the program's impact. The costs are associated with the need to test the technology in real-world conditions and gather data to inform future efforts (Seabin Project, 2021).

Litter Boom: $141,000 to $282,000

Planning and coordination expenses for litter boom technology range from $24,000 to $48,000. Similar to Seabin technology, these costs cover site assessments (Environmental Protection Agency, 2018), project management (Project Management Institute, 2021), and stakeholder engagement. The complexity of deploying litter booms, which are larger and more stationary than Seabins, contributes to these costs.

The procurement and installation of a litter boom can range from $65,000 to $130,000 per unit. The higher cost compared to Seabins is due to the larger size and more complex design of litter booms, which require more materials and labor for installation. Maintenance and monitoring costs are estimated at $17,000 to $34,000. Litter booms require regular inspections and debris collection to remain effective. Additionally, data collection and analysis are essential for assessing the technology's impact on reducing aquatic litter.

The pilot program and evaluation for litter boom Technology can cost between $35,000 and $70,000. This phase involves the initial deployment of the technology, engagement with the community, production of educational materials, and evaluation of the program's effectiveness. The costs are driven by the need to test the litter booms in various environments and gather data for future expansion.

Ultimately, both Seabin technology and litter boom technology require significant investments in planning, procurement, maintenance, and evaluation to effectively reduce aquatic litter. The costs are justified by the need for thorough assessments, effective management, community engagement, and rigorous evaluation to ensure the success of these initiatives.

Feasibility Assessment

The Seabin and litter boom initiatives demonstrate moderate feasibility, leveraging KAB's expertise in community engagement and environmental conservation to address plastic pollution in waterways. The initiative focuses on the strategic deployment of Seabins in calmer waters and litter booms in larger water bodies to capture floating debris. While the technology is proven, challenges lie in the expertise required for installation, maintenance, and monitoring. Funding and ongoing operations costs present potential hurdles, but partnerships with local businesses and government agencies offer financial and in-kind support. The initiative scores 27 out of 35 in feasibility, indicating a well-conceived program with some challenges to overcome, particularly in terms of long-term sustainability and scalability.

Funding and Financial Resources (3): The initiative requires funding for the purchase, installation, and monitoring of Seabins and litter booms. Potential sources include grants, corporate sponsorships, and local government support. However, the cost of maintenance and ongoing operations could pose a challenge. Partnerships with local businesses and government agencies can provide financial and in-kind support (Jambeck et al., 2015).

Technical Expertise and Infrastructure (4): The technology for Seabins and litter booms is proven and available. However, their installation and maintenance require technical expertise. The use of Seabins in contained or calmer water environments and litter booms in larger water bodies with high concentrations of floating debris is a strategic approach (Thiel et al., 2013). Coordinating logistics, conducting regular inspections, and evaluating their effectiveness will require dedicated personnel. KAB's experience in mobilizing volunteers and coordinating with stakeholders can support this aspect of the initiative (Ryan et al., 2009).

Community Engagement and Social Impact (4): The initiative's focus on coordinating with local authorities, businesses, and community organizations aligns with successful models of community engagement in environmental conservation (Saphores & Ogunseitan, 2017). Engaging volunteers in regular cleanup activities can foster a sense of ownership and responsibility toward local waterways. Raising public awareness about the impact of plastic pollution and the role of Seabins and litter booms in addressing it help engage the community and contribute to success (Jambeck et al., 2015).

Regulatory Compliance and Policy Alignment (3): Ensuring compliance with regulatory requirements and obtaining permits for installation in waterways are critical steps in the implementation process. Compliance with regulations may be challenging but manageable (Saphores & Ogunseitan, 2017).

Scalability and Replicability (3): The initiative can be scaled up by adding more units in other locations, but this is entirely dependent on funding and technical support. Implementing regular monitoring and data collection protocols allows for the evaluation of the effectiveness of Seabins and litter booms. GIS mapping and data analysis tools can be utilized to optimize coverage and assess environmental impact (Eriksen et al., 2014).

Partnerships and Collaborative Networks (4): The initiative's collaborative approach involving KAB, local governments, environmental agencies, businesses, and community organizations is crucial for its success. Shared goals and responsibilities can enhance cooperation among these entities. The involvement of Seabin manufacturers and grant providers in procuring equipment is also crucial (Ryan et al., 2009; Eriksen et al., 2014).

Long-term Sustainability and Impact (3): Addressing maintenance needs and operational challenges of Seabins and litter booms is essential for their long-term effectiveness and can be potentially difficult

(Thiel et al., 2013). The sustainability of the initiative depends on ongoing funding and community engagement. The initiative's multifaceted approach, involving technology deployment, community engagement, and collaboration with diverse stakeholders, requires effective project management. KAB's experience in managing environmental initiatives suggests they are capable of handling this complexity.

Equity Assessment

This initiative received an overall score of 6 out of 15, indicating significant barriers to equitable outcomes. While the initiative has some positive equity impacts, such as job creation and the potential to protect marginalized communities' access to clean ecosystems, it falls short in several key areas. Concerns include the equitable distribution of benefits, community involvement and empowerment, accessibility and inclusiveness, and addressing systemic issues. The reliance on corporate sponsors and the focus on end-of-pipeline solutions raise questions about the prioritization of community needs and the initiative's ability to address the root causes of plastic pollution.

Impact on Marginalized Communities (2): The implementation of technological solutions to address plastic pollution in waterways has several equity considerations regarding the outcomes of this policy alternative. As in the previous interventions, the reduction of plastic pollution in waterways has a positive impact on aquatic ecosystems and wildlife. This outcome has an equity dimension, as environmental degradation disproportionately affects marginalized communities who rely on natural resources for their livelihoods and cultural practices. By mitigating the harmful effects of waterway litter, the initiative can contribute to environmental justice by protecting these communities' access to clean and healthy ecosystems (Schlosberg, 2007; Agyeman, Bullard, & Evans, 2003). Moreover, the installation and maintenance of Seabins and litter booms can create job opportunities, particularly in areas with high unemployment rates. These jobs can provide valuable skills and income to marginalized communities, contributing to social and economic equity (Gibbs & O'Neill, 2014; Barbier, 2012).

Equitable Distribution of Benefits (1): There are concerns regarding the equitable distribution of these benefits. If the deployment of Seabins and litter booms is concentrated in areas with higher visibility or economic importance, such as tourist destinations or wealthier neighborhoods, it may neglect areas that are more environmentally sensitive or have higher needs due to historical pollution (Walker, 2009; Mohai, Pellow, & Roberts, 2009).

Community Involvement and Empowerment (1): The reliance on corporate sponsors and businesses for funding and support raises concerns about potential conflicts of interest and the prioritization of corporate interests over community needs. Ensuring that the initiative remains community-focused and transparent in its operations and partnerships is crucial for maintaining trust and credibility among all stakeholders (Gupta & Lebel, 2010; Littig & Griebler, 2005).

Accessibility and Inclusiveness (1): While these devices can effectively capture floating debris, their deployment does not inherently ensure accessibility and inclusiveness. The selection of locations for Seabins and litter booms may not involve direct consultation with community members, particularly those from marginalized groups. This lack of community engagement could result in the placement of these devices in areas that are more visible or economically important, rather than in locations where they are most needed based on environmental and social factors (Walker, 2009).

Addressing Systemic Issues (1): While Seabins and litter booms are effective tools for capturing existing waterway litter, they do not address the systemic issues that contribute to littering behavior or the production of litter. By focusing on the end-of-pipeline solution, this policy alternative may overlook the root causes of plastic pollution, such as overconsumption, inadequate waste management infrastructure, and lack of public awareness about the impacts of littering.

RECOMMENDATION

In light of the analysis conducted on various policy alternatives to address aquatic litter in the United States, I recommend the implementation of the Shifting Social Norms policy. This policy stands out across all categories, but specifically in its feasibility, equity, and cost. The initiative capitalizes on community engagement to foster responsible waste disposal practices. It is highly feasible, leveraging existing networks and resources with a score of 30 out of 35, and encourages volunteer participation, which helps keep operational costs low, ranging from $110,000 to $290,000. This policy's focus on education and awareness-raising ensures equitable distribution of benefits, scoring 13 out of 15 in equity, contributing to the overall well-being of the community. While not quite the most aggressive in terms of litter reduction, with an effectiveness of -24.87% to -25.02% and its potential for long-term behavioral change, it proves a sustainable and impactful choice. The emphasis on shifting norms helps to address the root cause of littering behavior and can lead to a lasting reduction in marine litter. In selecting this policy, feasibility and cost are prioritized because all alternatives are fairly effective, but the issue is urgent, requiring a focus on policies that are not cost-prohibitive or infeasible

Outcomes Matrix

Policy Option	Effectiveness	Cost	Feasibility	Equity
Community Education & Awareness	- 9.14% to - 19.86%	$215,000 to $515,000	26/35	10/15
Shifting Social Norms	-24.87% to -25.02%	$110,000 to $290,000	30/35	13/15
Aquatic Litter Capture Technologies	-19.67% to -25.35%	$291,000 to $552,000	24/35	6/15

Table 1. Multidimensional representation of the three policy alternatives evaluated across the four criteria, easing comparison of the alternatives. This table uses a "heat map" with the best scores in green and the worst in red. The alternative with the highest scores in the greatest number of criteria categories is bolded.

IMPLEMENTATION

The Shifting Social Norms initiative can be implemented through a pilot program led by Keep America Beautiful. This program should address the pressing issue of aquatic litter with an initial focus on urban settings, where the density of trash per square mile is notably higher. The comprehensive plan below outlines the steps for implementing a pilot program that leverages community engagement, public-private partnerships, and cutting-edge research to achieve its goals. The pilot program will span one year, with the first three months dedicated to preliminary planning and coordination, followed by volunteer recruitment and training in months four to six. Regular cleanup events, educational activities, and data collection will take place in months seven to nine, culminating in the evaluation of the pilot program and reporting in months ten to twelve.

PRELIMINARY PLANNING AND COORDINATION

The success of the initiative begins with meticulous planning and coordination. KAB must engage with a variety of stakeholders, including city officials, local environmental agencies, community organizations, and businesses, to build a coalition of support and collaboration (Dono et al., 2010). Ensuring that all stakeholders are engaged and have a sense of ownership in the initiative can be challenging but is necessary for its success. Sprengel & Busch (2001) emphasize the importance of inclusive stakeholder engagement in environmental initiatives. These partnerships will be crucial for identifying priority areas for cleanups, obtaining necessary permits, and coordinating resources. In planning, state and local environmental protection agencies and departments such as Environmental Quality or Natural Resources will be crucial, providing insights into environmental regulations and natural resource management. If present, the Office of Sustainability can offer guidance on aligning the initiative with broader sustainability goals. Utilizing Geographic Information Systems (GIS) technology, KAB will work with urban planning agencies to map out heavily littered areas, prioritizing sites for cleanup based on litter density, environmental sensitivity, and accessibility for volunteers (Valiente et al., 2020). Funding and resource allocation are critical at this stage, with a focus on securing grants, corporate sponsorships, and local government support to cover expenses related to cleanup supplies, volunteer training, and waste management. securing adequate funding and resources for cleanups, educational efforts, and monitoring activities is essential. Financial constraints can limit the scope and frequency of cleanups. Yilan et al. (2022) highlight the importance of sustainable financing mechanisms and resource allocation in the success of environmental initiatives.

VOLUNTEER RECRUITMENT AND TRAINING

Volunteers are the backbone of the initiative. KAB will employ diverse outreach channels, such as social media, community newsletters, and local events, to recruit volunteers from various demographics (Jorgensen et al., 2020). The Department of Public Works and Parks and Recreation Departments can assist in this phase by facilitating access to cleanup sites and helping recruit volunteers from the community. Local school boards and education departments can also play a role in engaging students and teachers in the initiative. Engaging community organizations like local chapters of Rotary Clubs or Scouts can also help in volunteer recruitment and community outreach. Maintaining a consistent and motivated volunteer base is crucial for the success of cleanup initiatives. Volunteer fatigue and fluctuating participation levels can hinder the effectiveness of regular cleanups. As noted by Measham & Barnett (2008), strategies for sustaining volunteer engagement include providing recognition, creating a sense of community, and offering incentives. Additionally, comprehensive training sessions will be provided to ensure volunteers are well-versed in safety protocols, proper handling of waste, and the overarching importance of their contribution to environmental conservation. Providing volunteers with necessary tools and supplies, such as gloves, bags, trash pickers, and first aid kits, is essential for their safety and effectiveness (Jorgensen et al., 2020).

TARGETED CLEANUP EVENTS

The initiative will feature regular cleanup events throughout the year, strategically scheduled based on factors like weather conditions, volunteer availability, and seasonal patterns of litter accumulation. The Parks and Recreation Departments will likely be crucial partners in organizing these events in public parks, beaches, and recreational areas. A systematic approach will be employed, dividing areas into sections and assigning teams to specific zones to maximize coverage and efficiency. Notably, small plastics and cigarette butts pose a particular challenge as they are often overlooked in cleanups and can have significant environmental impacts. Research underscores the importance of targeted strategies for removing these smaller items and the need for public education on their environmental consequences. Proper waste management practices, including the segregation of recyclable and non-recyclable materials, will be a key focus. The Department of Public Works can support waste management and disposal during these events. Educational tents at these events can raise awareness about the impacts of litter on the environment and promote responsible waste disposal practices. Developing informational materials and conducting workshops can further educate the public about the importance of keeping aquatic environments clean and healthy.

MONITORING AND EVALUATION

Monitoring and evaluation are crucial for assessing the effectiveness of the initiative. One of the primary challenges in implementing such initiatives is accurately measuring their impact on litter reduction and behavior change. Establishing reliable baseline data for litter levels can be difficult, and short-term assessments may not capture the full extent of behavioral changes. For example, a study by Singh and Kaur (2021) highlights the complexities of measuring the effectiveness of anti-littering campaigns, emphasizing the need for robust evaluation methods and long-term monitoring. Accordingly, KAB must implement standardized metrics such as litter weight collected, area coverage, and community feedback to gauge the impact of each event. Surveys on littering habits and monitoring litter levels before and after events will provide insights into behavioral changes and the overall success of the initiative. KAB should also monitor longer term littering levels (i.e. 3 months, 6 months, and 1 year post-intervention) in the area to understand how norms around littering are shifting. Regular reporting to stakeholders will highlight achievements and areas for improvement. Moreover, water management agencies can provide expertise in water quality and hydrology, which are important for assessing the impact of these clean-up efforts on aquatic ecosystems. The Department of Public Health can offer insights into the public health implications of aquatic litter.

SUSTAINABILITY AND LONG-TERM IMPACT

Ensuring the sustainability and long-term impact of the initiative requires ongoing community engagement, robust partnerships, and continuous education and awareness efforts. KAB will work to foster a sense of ownership and responsibility among local communities and volunteers, ensuring sustained involvement in the initiative. Strengthening collaborative networks with local governments, environmental agencies, businesses, and community organizations will enhance the reach and impact of the initiative. Ongoing educational campaigns will continue to raise public awareness about the importance of proper waste disposal and the environmental impacts of litter.

APPENDICES

APPENDIX I: ADDITIONAL TRASH CAPTURE TECHNOLOGIES

TRASH CAPTURE TECHNOLOGIES	
Storm Drain Inlet Trash Capture Technologies	
Curb Inlet Covers	Trash screens are designed to keep trash on the street and stop trash from entering the storm drain system. This way trash is kept on the street, so it can be swept up by street sweepers before it reaches the catch basin. The styles and sizes of openings differ, so these devices differ in their effectiveness.
Catch Basin Outlet Screens	Catch basin outlet screens are installed inside storm drains. These are screens or filters that block trash from entering stormwater intake pipes. Those with mesh size >5mm can be certified as 'full capture devices' in California. Often, screen systems will release trash if overflows occur.
Catch Basin Hoods	Catch basin hoods are installed in catch basins to prevent large floatable litter, such as aluminum cans and bottles, from entering sewers or stormwater pipes. They are not full-capture devices and must be used alongside other trash capture methods to ensure complete capture. To maximize the capture of both floatable and settleable trash, catch basin hoods should be equipped with anti-siphon devices and paired with deep-sump catch basins.
Catch Basin Fabric Inserts	Catch basin inserts are cost-effective and practical solutions for capturing trash in stormwater systems, especially in older infrastructure where other technologies might not be feasible or affordable. They typically consist of durable steel frames and fabric filters designed to withstand storms, debris, and maintenance activities. These inserts facilitate easy inspection and cleaning without needing to remove catch basin grates, offering a full capture solution.
In-Line and End of Pipe Trash Capture Technologies	
Linear Radial Devices	A Linear Radial Device consists of a louvered linear screen cage housed in a concrete vault. Trash and stormwater enter the cage, with water passing through the concrete structure while trash is captured inside the screen cage. Cleaning these units requires vacuum trucks and other trash removal tools. Adequate space is needed for maintenance, and installations can be shallow and open to the air. The screen openings can also be customized to suit specific needs.

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Hydrodynamic Separators	Hydrodynamic separators are commonly used in stormwater treatment to remove sediments, floatables, and other pollutants through a flow-through structure with a settling or separation unit. They vary in size, with some small enough to fit in conventional manholes, and use either swirl action or indirect filtration for separation. These separators are cleaned using vacuum trucks and have high flow capacity, typically ranging from 10 to 30 feet deep. Although engineering and installation costs can be high, these devices are durable and cover a large area. They can be installed as inline/online or offline units and can be pre-cast or cast-in-place, with the latter designed for greater flows but also higher construction costs due to deeper installations and consideration of nearby infrastructure
Netting Systems	Netting systems for stormwater management can vary in net size and design, with options for in-line or end-of-pipe installations. In-line netting systems are placed underground in concrete vaults, functioning similarly to linear removal devices. These systems feature one or more mesh bags held in place by a metal frame guide system. When the nets become full, they are replaced with new ones. End-of-pipe systems, which can be located at discharge points or collection areas like flood channels, are above ground and require regular inspections to check for and repair any damage caused by vandalism, etc.
Open Water Trash Capture Technologies	
Trash Skimmer Vessels	Netting systems for stormwater management can vary in net size and design, with options for in-line or end-of-pipe installations. In-line netting systems are placed underground in concrete vaults, functioning similarly to linear removal devices. These systems feature one or more mesh bags held in place by a metal frame guide system. When the nets become full, they are replaced with new ones. End-of-pipe systems, which can be located at discharge points or collection areas like flood channels, are above ground and require regular inspections to check for and repair any damage caused by vandalism, etc.
Bandalong Litter Trap	The Bandalong Litter Trap merges boom and skimmer technologies to collect litter in waterways. It floats on the surface, utilizing the current to direct debris into the trap, while anchors keep it stationary. The design allows fish to pass underneath it freely. These traps have been deployed in various locations, such as the Anacostia River in Washington, D.C., and the Proctor Creek Watershed in Atlanta, Georgia, where they are particularly effective after rain events.
Baltimore Harbor Trash Wheel	The Baltimore Trash Wheel innovatively utilizes the boom concept, featuring a solar-powered wheel with a conveyor belt. Harnessing energy from the sun and the river's current, the wheel rotates, lifting garbage and debris, including items as large as tires and mattresses, up the conveyor belt and into a dumpster for land-based disposal.

Source: EPA (2023)

APPENDIX II: EFFECTIVENESS CALCULATIONS

COMMUNITY EDUCATION AND AWARENESS							
Variable	Baseline	Policy Implementation	PD	ES	PI	EA	% Δ
Coefficient	-0.05	-0.2	0.005	-0.003	-0.007	-0.004	
Good Implementation							
Urban City	1	0.72	2553	50989	6	7	-0.1986
Baseline CIty	1	0	1600	37585	4	4	
Rural City	1	0.72	900	46891	2	2	-0.1914
Poor Implementation							
Urban City	1	0.22	2553	50989	6	7	-0.0986
Baseline City	1	0	1600	37585	4	4	
Rural City	1	0.22	900	46891	2	2	-0.0914

SHIFTING SOCIAL NORMS							
Variable	Baseline	Cleanup	PA	VE	U	TA	% Δ
Coefficient	-0.05	-0.2	-0.002	-0.0015	0.003	0.002	
Urban City	1	1	6	6	7	7	-0.2487
Baseline City	1	0	4	4	4	5	
Rural City	1	1	2	2	3	2	-0.2502

AQUATIC LITTER CAPTURE TECHNOLOGIES							
Variable	Baseline	Seabin	Litter boom	PD	PI	EA	% Δ
Coefficient	-0.05	-0.2	-0.15	0.005	-0.007	-0.004	
Urban City	1	1	0	2553	6	7	-0.2535
Baseline City	1	0	0	1600	4	4	
Rural City	1	0	1	900	2	2	-0.1967

APPENDIX III: ITEMIZED COST BREAKDOWNS

COMMUNITY EDUCATION & AWARENESS

Planning and Development:

- Research and Analysis: $20,000 - $50,000 (includes hiring consultants, data collection, and analysis)
- Strategy Development: $10,000 - $30,000 (includes identifying target audiences, setting goals, and outlining the campaign plan)
- Project Management: $15,000 - $40,000 (includes staff salaries and administrative costs for managing the project)

Educational Material Development:

- Content Creation: $30,000 - $60,000 (includes writing, designing, and producing educational materials like brochures, posters, and online content)
- Printing and Distribution: $20,000 - $50,000 (includes printing costs and distribution logistics for physical materials)

Workshops and Events:

- Event Planning and Coordination: $25,000 - $50,000 (includes venue rental, logistics, and coordination for workshops and events)
- Promotional Activities: $15,000 - $35,000 (includes advertising and promotional materials to attract participants)
- Participant Engagement: $10,000 - $25,000 (includes materials, refreshments, and incentives for participants)

Community Outreach:

- Outreach Personnel: $30,000 - $60,000 (salaries for outreach coordinators and staff)
- Travel and Logistics: $10,000 - $30,000 (includes transportation and accommodation for outreach activities)
- Community Engagement: $15,000 - $40,000 (includes costs for community meetings, local advertising, and engagement initiatives)

Ongoing Evaluation and Monitoring:

- Data Collection and Analysis: $10,000 - $30,000 (includes costs for collecting feedback, surveying participants, and analyzing the impact of the campaign)
- Reporting: $5,000 - $15,000 (includes costs for preparing and disseminating progress reports and final evaluations)

Total Estimated Cost: $215,000 - $515,000

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SHIFTING SOCIAL NORMS

Planning and Coordination:

- Site Assessments: $10,000 - $30,000 (includes environmental assessments of waterways, beaches, and coastal areas)
- Project Management: $20,000 - $50,000 (includes staff salaries and administrative costs for managing the initiative)
- Partnership Development: $5,000 - $15,000 (includes costs for establishing collaborations with local partners and stakeholders)

Volunteer Recruitment and Training

- Outreach and Recruitment: $10,000 - $25,000 (includes advertising, social media campaigns, and community outreach to recruit volunteers)
- Training Sessions: $5,000 - $15,000 (includes costs for organizing training sessions on safety protocols, waste handling, and environmental conservation)

Cleanup Events

- Supplies and Equipment: $15,000 - $35,000 (includes gloves, bags, trash pickers, first aid kits, and other necessary tools for volunteers)
- Logistics and Coordination: $20,000 - $50,000 (includes costs for organizing and coordinating cleanup events, including transportation, refreshments, and waste disposal)
- Educational Tents and Materials: $10,000 - $25,000 (includes costs for setting up educational tents and producing informational materials for awareness-raising)

Monitoring and Evaluation:

- Data Collection and Analysis: $10,000 - $30,000 (includes costs for monitoring litter levels, surveying community behavior, and evaluating the impact of cleanups)
- Reporting: $5,000 - $15,000 (includes costs for preparing and disseminating progress reports and impact assessments)

Total Estimated Cost: $110,000 - $290,000

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WATERWAY LITTER CAPTURE TECHNOLOGY

Seabin Technology (for 10 Seabins)

Assessment and Planning:

- Site Assessments: $10,000 - $20,000 (includes environmental assessments and identifying suitable locations for Sea Bin deployment)
- Project Management: $15,000 - $30,000 (includes staff salaries and administrative costs for managing the initiative)
- Stakeholder Engagement: $5,000 - $10,000 (includes costs for engaging with local authorities, businesses, and community organizations)

Sea Bin Procurement and Installation:

- Sea Bin Purchase: $4,000 per unit
- Installation Costs: $2,000 - $4,000 per unit (includes anchoring, connectivity to power sources, and regulatory compliance)
- Transportation and Logistics: $1,000 - $3,000 per unit (includes costs for transporting and installing Sea Bins at designated locations)

Maintenance and Monitoring:

- Regular Inspections: $500 - $1,000 per unit per year (includes costs for inspecting and maintaining Sea Bins)
- Data Collection and Analysis: $10,000 - $20,000 (includes costs for monitoring Sea Bin effectiveness and evaluating environmental impact)

Pilot Program and Evaluation:

- Pilot Implementation: $20,000 - $40,000 (includes costs for the initial deployment of Sea Bins, monitoring, and community engagement during the pilot phase)
- Educational Materials: $5,000 - $10,000 (includes costs for producing and distributing informational materials about Sea Bins and marine conservation)
- Evaluation and Analysis: $10,000 - $20,000 (includes costs for evaluating the pilot program and adjusting deployment strategies for scaling up)

Total Estimated Cost for 10 Sea Bins: $150,000 - $270,000

Litter Boom Technology (for 1 litter boom)

Assessment and Planning:

- Site Assessments: $8,000 - $15,000 (includes environmental assessments and identifying suitable locations for Litter Boom deployment)
- Project Management: $12,000 - $25,000 (includes staff salaries and administrative costs for managing the initiative)
- Stakeholder Engagement: $4,000 - $8,000 (includes costs for engaging with local authorities, businesses, and community organizations)

Litter Boom Procurement and Installation:

- Litter Boom Purchase: $50,000 - $100,000 per unit (varies based on size, materials, and technology)
- Installation Costs: $10,000 - $20,000 per unit (includes anchoring, positioning, and regulatory compliance)
- Transportation and Logistics: $5,000 - $10,000 per unit (includes costs for transporting and installing Litter Booms at designated locations)

Maintenance and Monitoring:

- Regular Inspections: $2,000 - $4,000 per unit per year (includes costs for inspecting and maintaining Litter Booms)
- Debris Collection and Disposal: $5,000 - $10,000 per year per unit (includes costs for regularly removing captured litter and proper disposal)
- Data Collection and Analysis: $10,000 - $20,000 (includes costs for monitoring Litter Boom effectiveness and evaluating environmental impact)

Pilot Program and Evaluation:

- Pilot Implementation: $20,000 - $40,000 (includes costs for the initial deployment of Litter Booms, monitoring, and community engagement during the pilot phase)
- Educational Materials: $5,000 - $10,000 (includes costs for producing and distributing informational materials about Litter Booms and marine conservation)
- Evaluation and Analysis: $10,000 - $20,000 (includes costs for evaluating the pilot program and adjusting deployment strategies for scaling up)

Total Estimated Cost for a Litter Boom: $141,000 to $282,000

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