Towards Sustainable Funding and Synergistic Management of Neglected Tropical Diseases

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Abstract

Neglected tropical diseases (NTDs) such as schistosomiasis impact over one billion people worldwide, primarily in low- and middle-income countries, as highlighted by the World Health Organization. Despite their widespread prevalence and severe health consequences, these diseases remain poorly understood and significantly underfunded. This research seeks to address the gap in funding and treatment by developing sustainable solutions that integrate environmental and ecological considerations, especially in regions with high co-infection rates. We examine two particular strategies: that of mass drug administration (MDA) and sustainable vector control through vegetation removal. While MDA campaigns have proven cost-effective in preventing NTDs, their true costs and benefits extend beyond immediate drug expenses. Through cost-benefit analyses and life cycle sustainability assessments, this study evaluates the long-term effectiveness of these campaigns. Additionally, we examine the scalability and environmental sustainability of a targeted vector control strategy - vegetation removal - to reduce the prevalence of vector-borne NTDs like schistosomiasis. The outcomes of this research include an optimized strategy for reducing disease prevalence, improving long-term health outcomes, and promoting socio-economic development in affected regions, ultimately advancing global health equity.

Introduction

Over the past decade, significant strides have been made toward controlling and eliminating neglected tropical diseases (NTDs). According to the World Health Organization, the number of people requiring NTD interventions decreased by 80 million between 2020 and 2021, and several countries have successfully eliminated at least one NTD. However, achieving the 2030 targets outlined in the WHO's road map remains a formidable challenge, exacerbated by COVID-19 disruptions, geopolitical instability, and the impacts of climate change.

Despite these advancements, there remains a critical need for sustainable strategies that address the long-term management of NTDs, particularly in regions with high co-infection rates and complex environmental factors. Addressing these challenges requires integrated and adaptable approaches that encompass both health interventions and environmental sustainability.

This research builds on previous studies that have demonstrated the effectiveness of mass deworming and community-wide initiatives in reducing disease prevalence. Additionally, it explores the role of sustainable vector control strategies, particularly vegetation removal, as a means of reducing the prevalence of vector-borne NTDs like schistosomiasis. This study evaluates these approaches, focusing on their effectiveness, scalability, and long-term impact on public health outcomes. By employing advanced tools for comprehensive cost-benefit analysis and life cycle sustainability assessment, this research aims to identify optimized strategies that not only reduce the disease burden but also enhance socio-economic development, leading to more equitable health outcomes on a global scale.

Methods

Vegetation removal against Schistosomiasis

Schistosomiasis mansoni, the causative agent of schistosomiasis, was the focus of our vector control analysis. We employed a life cycle assessment (LCA) to evaluate the stages of vegetation removal, focusing on its environmental and economic implications.

To source and synthesize relevant research, we utilized AI-enabled literature search tools such as Consensus.app and Perplexity.ai. These tools were chosen for their ability to rapidly identify and curate pertinent literature, which was crucial for building a comprehensive understanding of our research topic. We also conducted targeted searches on Google Scholar using specific keywords like "Schistosomiasis vector control" and "Schistosomiasis, vegetation removal."

We visualized the relationships and processes involved in vegetation removal using Kumu.io, a visualization software widely recognized for its capacity to map complex systems. This visual representation was essential in our comprehensive cost-benefit analysis, allowing us to clearly delineate the steps, costs, and benefits associated with the vegetation removal strategy.

The analysis was further supported by data from a trial conducted in the St. Louis Toll region of northern Senegal, accessed via Zenodo.org. This data was instrumental in calculating the monetary value in USD per person per trial year, providing a robust assessment of the economic viability of the strategy.

Mass Drug Administration

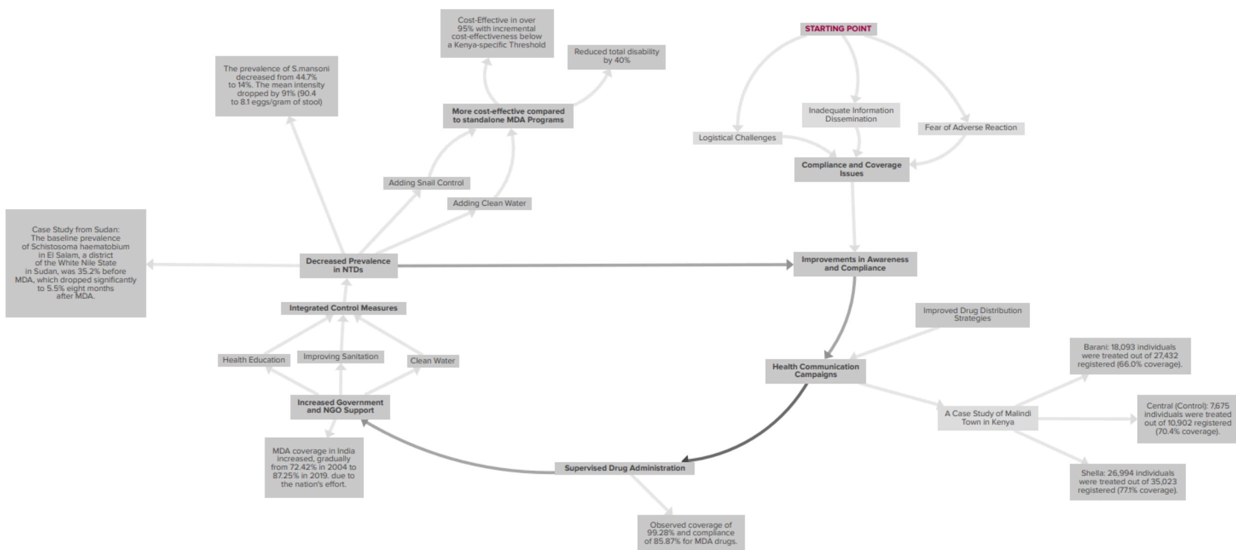
Program

We used Kumu.io to map our findings regarding the complexities of Mass Drug Administration for NTDs. We moved through several possible solutions to real-world cases and synergized these insights to show how approaches can be integrated to reduce prevalence of NTDs. To find relevant data for building a complete understanding of the subject, our research referred extensively to relevant articles from PubMed, ScienceDirect, PLOS, and other credible sources.

We collected a complex of data ranging from a variety of sources based on our literature review and then illustrated in Figure 1 the comprehensive strategy of MDA based on community engagement, health communication, and control measures, such as improved sanitation and clean water. In this report, we elaborate on the features, costs, and benefits of each aspect of the diagram.

Figure 1: Mapping the Impact of Mass Drug Administration (MDA) on Combating Neglected Tropical Diseases (NTDs): Challenges, Strategies, and Outcomes

The high-resolution Figure 1 can be found at: [Life-Cycle Assessment of MDA]



Compliance and Coverage Rules

One finding is that our system-level diagram presents an ideal campaign, whereas in our research we specifically seek to understand how logistical challenges, poor information dissemination, and fear of adverse reactions impact MDA coverage. We note that in Southern Mozambique, logistical difficulties - the absenteeism of household heads or problems in drug delivery - raise a myriad of problems for participating in the MDA program. [Cuinhane et al. (2023)]. Another finding is that, in the absence of sufficient information supply, it gives way to misconceptions and the reluctance to take part as seen in cases where the use of better communication strategies formed a crucial part of community mobilization. [Nath et al. (2019)] In Orissa, India, we observed that the other major cause of non-adherence is the fear of the side effects as 49.5% of the population ceased to take MDA drugs for this reason. [Babu and Mishra (2008)] On the other hand, increased awareness and motivation among health workers have a sizable impact on participation. Addressing these issues, therefore, is a necessary strategy towards an effective MDA program.

Improvements in Awareness and Compliance by Incorporating Health Communication Campaigns

Inclusion of health communication campaigns in MDA programs enhances awareness and lays a better foundation for compliance by tackling some of the underlying barriers. For instance, effective communication allays fears of adverse reactions and explains the gains expected from drug uptake, hence building trust and participation within communities. This means that improved distribution strategies, such as direct observation or community engagement, if combined with campaigns, would indeed synergize and strongly improve the coverage rates. This strategy thus helps to deal with not only logistical issues in order for drugs to reach the targeted populations but also surmounts some of the hesitancy emerging from misinformation or lack of awareness regarding the various health initiatives. Ultimately, this combination of strategic communication and distribution leads to increased participation and compliance rates in various regions, resulting in more successful MDA outcomes [Njomo et al. (2014)].

Supervised Drug Administration

This is followed by the observation that supervised drug administration makes a great influence on the increase in coverage and compliance rates of MDA. In the case of Dhenkanal district, Odisha, India, the reported coverage rate after supervised drug administration is 99.28%; its compliance rate is 85.87%. This approach directly works on the common barriers related to logistical problems, fears of side effects, and mistrust of the health providers by ensuring that drugs are taken and the immediate worries attended to. Having health workers present at the time of drug administration instills confidence in the community and largely reduces the opportunity for noncompliance. This would help to ensure a high level of participation not only in and of itself, but also to create a benchmark for other similar regions facing challenges in their MDA programs. [Ratna et al. (2024)]

Increased Government and NGO Support

High governmental and NGO support significantly increases the MDA coverage over time, which was a fact found in our study. In India, this has been a key factor in the gradual improvement in MDA coverage from 72.42% in 2004 to 87.25% in 2019. In this regard, the government-NGO collaboration improved the planning of allocation of resources and increased the reach of health awareness campaigns with stringent monitoring systems. This coordinated effort does not only improve the coverage of MDA programs; working through such problems as logistical barriers and community resistance, it achieves more sustainable health outcomes. It is this continued engagement with these stakeholders that will be required to sustain and further increase MDA coverage, bringing it closer to the goal of eliminating neglected tropical diseases like lymphatic filariasis in endemic regions. [Ratna et al. (2024)]

Decreased prevalence in NTDs

Support integration from the government and NGOs has played an important role in achieving the current prevalence reduction. For instance, the continued MDA campaign in White Nile State, Sudan, that reduced the prevalence of schistosomiasis from 35.2 percent to 5.5 percent is, succinctly, very indicative of strategic allocation of resources and community engagement towards executing impactful results [Cha et al. (2020)]. In Kenya, the complementarity among health education, improved sanitation, and MDA programs helped further enhance compliance and coverage, illustrating the compounded benefits of holistic approaches to public health interventions [D. Njomo et al. (2012)]. The synergy between these elements - where support from governments and NGOs catalyzes better health communication and logistical planning - has therefore led to the sustainable reduction in neglected tropical diseases. It, therefore, calls for continued collaboration and investment to sustain public health milestones in endemic regions.

Cost Analysis

Table 1: Cost Analysis of MDA Programs in Kenya

Components	Cost per person per round	Cost per Person per Completed Campaign (2 Rounds per Year)	Total Cost for 100,000 People (per Round)	Total Cost for 100,000 People (per complete campaign)	Sources
A dose of Praziquantel	$0.98	$1.96	$98,000	$196,000	Mwinzi et al. (2012)
A dose of Albendazole	$0.23	$0.46	$23,000	$46,000	Mwinzi et al. (2012)
Combined Treatment in Children	$0.95	$1.90	$95,000	$190,000	Kolaczinski et al. (2011)
Individual Community Health Worker: $4 per CHW (10 of them needed for a round of MDA campaign)	$40	$80	$4,000,000	$8,000,000	Odhiambo et al. (2016b)
Individual Village Elder: $2 per VE (5 of them are	$10	$20	$1,000,000	$2,000,000	Odhiambo et al. (2016b)

needed for a round of MDA campaign)					
Initial cost of Health Campaign	$41.66	$83.32	$4,166,000	$8,332,000	Kahn et al. (2011)
Health Campaign After Campaign Scaled Up	$31.98	$63.96	$3,198,000	$6,396,000	Kahn et al. (2011)
Clean Water	$0.08	$0.16	$8,000	$16,000	Freedman et al. (2017)
Improving Sanitation in Primary Schools (WASH infrastructure)	$4.92	$9.84	$492,000	$984,000	Alexander et al. (2016)

Note: According to Alexander, the cost of installing or setting up WASH infrastructure, which was US$18,916 per primary school in Kenya, for a school of 400 students (US$4.92 per student per year)

Table 2: Community Health Worker (CHW) Service Metrics and Resource Requirements in Kenya

Components	**Data**
Number of households per CHW	10 households
Average number of persons per household	4 persons
Total number of individuals per CHW	40 individuals
Time spent per household event	2 hours
Number of days worked per month by CHW	5-10 days
Total hours worked per month by CHW	20-40 hours (2 hours/visit)
Total households visited per month	10 households
Primary health services provided by CHW	Health education, vaccinations, and basic medical care

Total number of CHWs required to cover a population of 100,000 people	2,500 CHWs

Source: Rifkin (2017)

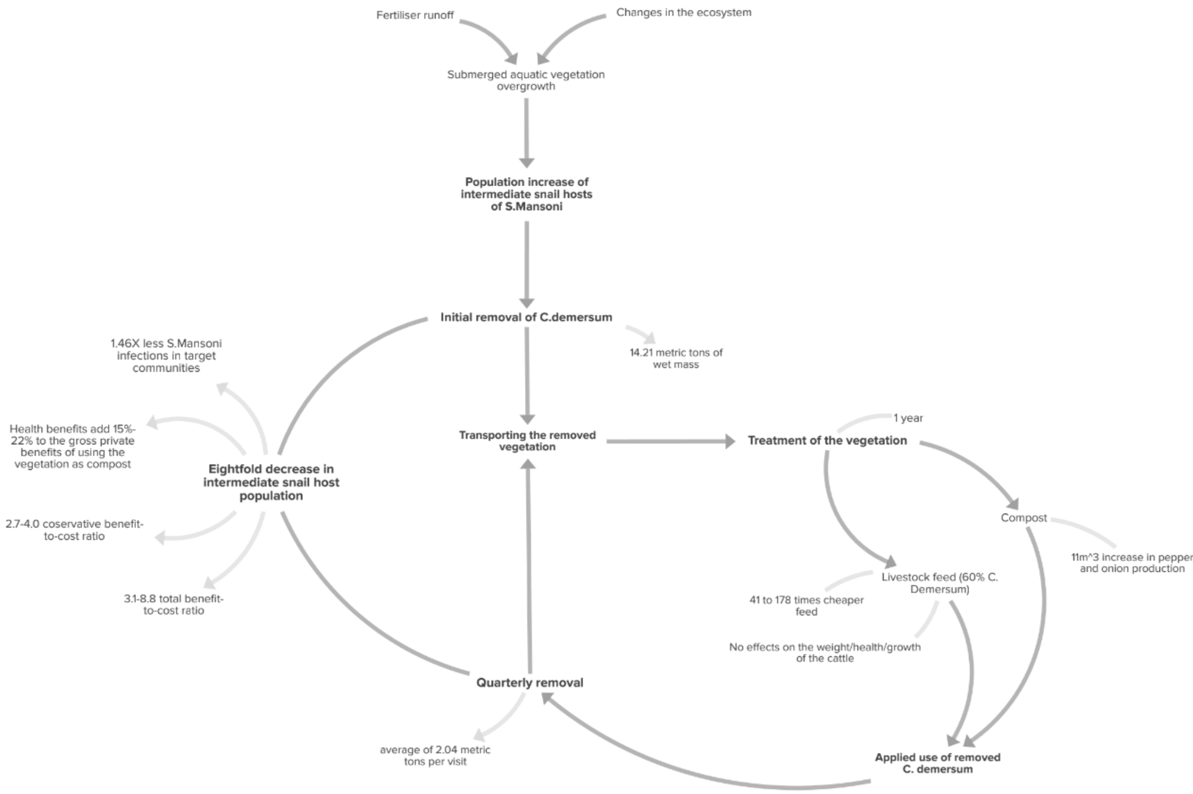
In conclusion, our diagram and tables underscore how cost allocation, resource management, and the success of the MDA program are critically linked. In this cost analysis table, one can see large investments, like that of US$40 per person for CHWs or US$4.92 per person for sanitation. Such costs are very necessary, as this diagram proves that a well-trained CHW had a 85.87 percent compliance rate and a schistosomiasis prevalence reduction from 35.2 percent to 5.5 percent. Those relationships therefore mean that although the MDA programs are very expensive at the beginning, they are overridden by their long-term health benefits and cost efficiencies. In the same vein, the integration of sanitation and clean water reflected in the tables corresponds with the mind map focused on integrated control measures relevant to success. In general, the data support strategic investment in CHWs and sanitation as a drive toward effectiveness in both immediate and long-term programs.

Vegetation Removal for Schistosomiasis

In a similar strategy to that of our MDA cases, we analyzed a campaign for the direct removal of vegetation that removes the habitation for the snail intermediate host of the parasite. Then we further compare the two cases. We started our research by working on a life cycle assessment of the vegetation removal strategy. We then worked on a cost benefit analysis for the same.

Figure 2: Diagram representing the progression of vegetation (*C. demersum*) removal for *S. mansoni* vector control.

The high-resolution Figure 2 can be found at: Vegetation Removal Diagram.pdf



This analysis elaborates on the ecological management strategy depicted in the diagram, focusing on the removal of the aquatic plant *Ceratophyllum demersum* (*C. demersum*) and its impacts on the ecosystem, human health, and economic benefits. The strategy addresses the overgrowth of *C. demersum*, which provides a habitat for snails carrying the *Schistosoma mansoni* (*S. mansoni*) parasite, the causative agent of schistosomiasis.

Cost-benefit Analysis

In our cost-benefit analysis, we present both conservative and total benefit-to-cost ratios. The conservative ratio, ranging from 2.7 to 4.0, considers only direct costs and benefits, such as the costs of removal and immediate reductions in snail populations. The total ratio, ranging from 3.1 to 8.8, includes comprehensive benefits, such as improved public health and increased agricultural productivity. This analysis highlights the high return on investment from the ecological management and intervention strategy.

The raw data for the costs is unobtainable with the resources we have. We have obtained the individual monetary benefits of using the vegetation as compost and as feed through calculating the difference between the costs of commercial, widely used feed/compost in the area of the trial, and the production costs of *C. demersum* based feed/compost. The value is US$1.51 per person per year for compost, and US$0.9 per person per year for the feed. To calculate the health benefits of vegetation removal, we multiplied the averted DALYs (Disability-Adjusted Life Year) by the GNI (Gross National Income) per capita of Senegal. The results ranged from US$548 to US$16,452 throughout the villages, with a median of US$1,645 and an average of

US$5,072. This drastic difference is explained by the variance of disability weight prior to conducting the vegetation removal trial.

We sourced the data for production costs and health benefits from the database of the North Senegalese trial available on Zenodo. The value of original commercial compost and feed were procured through the Google and Bing search engines using the keywords "Senegal alimentation moutons chèvres" and "Senegal engrais poivrons onions".

Initial Conditions and Problem Statement

The initial condition described in the diagram identifies fertilizer runoff and ecosystem changes as primary contributors to the overgrowth of submerged aquatic vegetation. This overgrowth creates a suitable environment for intermediate snail hosts of the *S. mansoni* parasite. These snails play a crucial role in the parasite's life cycle, temporarily harboring the larvae until they mature and are released into the water, posing a significant health risk to humans who come into contact with contaminated water.

Intervention Strategy: Removal of *C. demersum*

The first step in the intervention strategy is the initial removal of *C. demersum*, which resulted in the extraction of 14.21 metric tons of wet biomass. This removal significantly reduces the habitat available for the intermediate snail hosts and sets off a series of ecological and economic processes aimed at controlling the population of these snails and the associated health risks.

Transportation and Treatment of Removed Vegetation

Following the removal, the harvested *C. demersum* biomass is transported for treatment using carts. The biomass is then processed in two main ways:

- Compost Production: The treated biomass is converted into compost, which improves soil quality and enhances agricultural productivity. This conversion led to an increase of 11 cubic meters in pepper and onion production in Northern Senegal. Using the compost not only boosts crop yields but also provides health benefits that add 15% to 22% to the gross private benefits, as healthier individuals contribute more effectively to agricultural activities.
- Livestock Feed: Another application of the treated biomass is its use as livestock feed, with 60% composition of *C. demersum*. This feed is 41 to 178 times cheaper than conventional feed and has been shown to have no negative effects on the weight, health, or growth of the cattle. This cost-effective feed alternative provides substantial economic savings for livestock farmers.

The treatment process takes approximately one year, highlighting the extended timeline required for the full realization of the intervention's benefits.

Ongoing Removal and Sustainability

To ensure that the ecological balance is maintained and the overgrowth problem does not recur, quarterly removals of C. demersum are implemented. This regular intervention helps keep the snail population under control and sustains the positive effects achieved from the initial removal.

Impact on Snail Population and Health Outcomes

The ongoing removal and treatment of *C. demersum* resulted in an eightfold decrease in the population of intermediate snail hosts. This significant reduction in snail populations directly correlates with a 1.46 times decrease in *S. mansoni* infections in the target communities, demonstrating a substantial improvement in public health. The target communities include not only the areas directly involved in the removal but also other regions that share the same water sources, extending the health benefits across a broader area.

Economic and Health Benefits

Using *C. demersum* as compost and livestock feed presents significant economic advantages. The health improvements due to fewer schistosomiasis infections contribute to the overall economic benefits, adding 15% to 22% to the gross private benefits. This dual benefit of better health and increased agricultural productivity underscores the value of this ecological management approach.

Discussion

In terms of effectiveness, vegetation removal is more targeted towards controlling the snail population which indirectly reduces disease transmission. MDA directly addresses the disease burden through widespread drug administration and has proven highly effective in reducing the prevalence and intensity of schistosomiasis.

Vegetation removal also offers a good benefit-to-cost ratio but may require ongoing investment and logistical effort. MDA demonstrates high cost-effectiveness with significant reductions in disease prevalence and disability, supported by additional integrated measures Vegetation removal needs continuous management and may have varying ecological impacts; however, it provides additional benefits like compost and feed. MDA is proven to be highly effective in the short term, but long-term sustainability requires consistent funding and community engagement, along with complementary interventions.

Combining both strategies could offer a comprehensive approach, as vegetation removal can reduce the intermediate host population, enhancing the impact of MDA by reducing the reservoir of infection. MDA provides direct treatment for affected individuals while complementary measures improve overall disease control. While a 7% increase in private benefit is modest, the underlying external public benefit of reduced infection risk, long term health and productivity benefits are compounding. This further supports a dual MDA, vector control campaign.

Future studies could delve into finding the balance between how Mass Drug Administration (MDA) is carried out and the level of effort put into removing vegetation, for example by investigating the ideal balance between MDA frequency and the intensity of vegetation removal efforts. Furthermore, it would be valuable to explore how scaling up vegetation removal in settings impacts health outcomes and local economies in the long run. It is crucial to integrate these strategies with public health interventions like sanitation and access to clean water to ensure sustainable control of diseases like schistosomiasis and other neglected tropical diseases. We discuss various methods and modalities to further study and bring about these changes. Overall, the focus should be on optimizing the combination of MDA and vegetation removal for cost effectiveness and control.

Further Research Recommendations

The effectiveness and sustainability of vector control strategies, particularly vegetation removal, offer significant potential in improving global health outcomes by reducing vector populations and disease transmission. However, the scalability of these interventions for global implementation remains a critical challenge. Future research must focus on the adaptability of these strategies to diverse ecological settings and socio-economic contexts. For instance, while the introduction of predatory prawns to control snail populations in schistosomiasis-endemic areas has demonstrated promise, successful implementation would require precise adaptation to specific local environmental conditions to ensure effectiveness [Sokolow et al. (2014)].

Further investigation is necessary to understand the role of real-time epidemiological surveillance systems in detecting early signs of praziquantel resistance, particularly in rural and resource-limited settings such as those in Kenya. The integration of mobile data collection tools with existing local health infrastructure could enhance the timely identification of resistance patterns, thereby maintaining the efficacy of mass drug administration (MDA) programs [Ismail et al. (1996)].

Behavioral change communication (BCC) strategies tailored to specific demographic groups are also critical in addressing cultural and social barriers that impede participation in MDA campaigns. In Kenya, the effectiveness of using local languages and culturally relevant messaging at the school and community levels to improve adherence and reduce reinfection rates has been well-documented. Future research should aim to refine these strategies further, exploring their application across various demographic groups to enhance the overall effectiveness of MDA initiatives [Omedo et al. (2012)].

The integration of mobile health (mHealth) technologies into MDA campaigns also presents a valuable area for further study. These technologies, which facilitate real-time data collection and treatment tracking, have the potential to increase the coverage and monitoring of MDA efforts, particularly in remote and underserved regions. Research should explore how mHealth platforms can be more effectively incorporated into public health strategies to improve MDA outcomes and overall health system efficiency [Toda et al. (2017)].

Finally, the implications of climate change on the distribution and intensity of schistosomiasis transmission must be a priority in future research. Changes in environmental conditions due to climate change may create favorable habitats for the parasite, necessitating the development of adaptive strategies. These could include flexible MDA schedules and enhanced environmental surveillance. Continued research is essential to develop and implement these strategies, ensuring that schistosomiasis control efforts remain effective and sustainable in the face of evolving climatic challenges [Rohr et al. (2023)].

Conclusion

Both MDA and vegetation removal offer substantial benefits in controlling schistosomiasis by addressing different aspects of the disease's transmission cycle. A combined approach, along with improved sanitation and clean water access, presents a comprehensive strategy for managing schistosomiasis. Effective cross-sectoral collaboration and continued research to optimize these strategies can further enhance their impact and cost-efficiency. By integrating environmental and ecological considerations with public health strategies, we can ensure that these interventions remain sustainable and effective over the long term.

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