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20TH CENTURY DISEASE ERADICATION PROGRAMS & THEIR LEGACIES FOR HEALTH SYSTEMS

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TABLE OF CONTENTS

Abbreviations	
EP	Eradication Program
GIS	Geographic Information System
GWD	Guinea Worm Disease
IMS-Dengue	Integrated Management Strategy for Dengue Prevention and Control
NTDs	Neglected tropical diseases
PAHO	Pan American Health Organization
TCP	Treponematoses Control Program
UN	United Nations
WHO	World Health Organization

EXECUTIVE SUMMARY

Covid-19 has disrupted health programmes worldwide, strained resources and prompted a reshuffling of priorities. In this context, stakeholders have been revisiting the Global Polio Eradication Initiative strategy, and wrestling with the question of what it means to integrate polio eradication activities into broader health systems. This working paper examines the legacies that six large-scale international disease eradication programs (EPs) conducted over the past century have left for health systems. The document analyses how EPs impacted the 'building blocks' of health systems (WHO, 2006); the intentions and timing of integration, challenges, and lessons learned. The EPs we analyse include:

- Rockefeller Sanitary Commission for the Eradication of Hookworm Disease (1909–15)
- Continental Plan for the Eradication of the Ae. aegypti (1947–70)
- Global Control of Treponematoses Program (1952–64)
- Global Malaria Eradication Program (1965–70)
- Global Smallpox Eradication Program (1966–80)
- Guinea Worm Disease Eradication Campaign (1991–present)

This research found evidence that EPs left important and useful legacies for the building blocks of health systems (HS). In addition, EPs had impacts beyond national health systems, including in community networks; contributions to gender equity; and intergovernmental and regional collaborations. Furthermore, all EPs ultimately had to address the question of integration, whether through integration of assets post-eradication or integration into HS in order to continue activities; however integration did not always benefit health systems, nor EPs.

1 | INTRODUCTION

Over the 20th century several large-scale international disease eradication programs were constructed with the aim to eliminate pathogens or their vectors. This working paper examines how six major eradication programs impacted health systems, and aims to draw lessons for contemporary efforts to eradicate disease. The eradication programs we analyse include: the Rockefeller Sanitary Commission for the Eradication of Hookworm Disease (1909–15); the Continental Plan for the Eradication of the Ae. aegypti (1947–70); the Global Control of Treponematoses Program (1952–64); Global Malaria Eradication Program (1965–70); Global Smallpox Eradication Program (1966–80); and the Guinea Worm Disease Eradication Campaign (1991–present).

Some eradication programs (EPs) resulted in sharp declines in disease incidence across entire countries and regions throughout Africa, Asia, and the Americas. However, most EPs were not able to sustain their impact on local epidemics. Analysts have identified several potential underlying reasons why most programs did not create lasting impacts on disease, ranging from changing conditions in the ecology of disease in different contexts to an inability to sustain political will and resources to support disease-specific programs, which often operated autonomously, outside of the healthcare structure in a given country. And given the persistent prevalence of many diseases that have been targeted for eradication, the 'success' of the campaigns has been evaluated critically by many observers. However, it is important to look beyond the disease eradication objective itself for a better understanding of the broader implications and impacts of EPs on health systems, at both international and national levels.

Historians have documented ways eradication programs (EPs) have been integral to the development of the field of 'international health' (Packard, 2016) and its evolution into "global health" today. EPs have been some of the "largest, most logistically complex, and costly initiatives" attempted over the history of international public health (Stepan, 2019), spanning national and international levels, coordinating across international organizations (e.g. UNICEF, WHO), and garnering support from prominent philanthropic organizations. Some have recognized the "mutually reinforcing" elements of eradication and basic health care, and highlighted differences among programs. Compared to early programs, the more recent EP have carried forward "the ideals of preventive medicine and basic health care" while also putting a dent in disease trajectories (Stepan, 2019). But concerns have also been raised that siloed disease eradication initiatives could weaken health

systems by drawing funding, attention and staff away from providing day-to-day health services.

Shortly before the new millenium, a group of directors from past programs and other authorities in disease control evaluated how future eradication programs should be integrated within health systems. Outlining the opportunities offered by well-designed EPs, they suggested such programs should support the creation and refinement of national health policies, promote the priorities of multiple stakeholders, and deliver services that go beyond the aim of eradication itself. They also contended that EPs should account for existing health system structures, integrate into those systems, and expand their objectives beyond immediate goals. However, for such EPs, there were concerns that financial and human resources would be diverted toward other activities, and disrupt eradication activities. They concluded future EPs should focus on weak and fragile health systems, where their contributions would have the greatest impact, and urged future vertical programs to extend through horizontal control activities (Melgaard et al., 1998).

Drawing lessons for disease eradication and control initiatives, this paper aims to understand how past EPs impacted health systems, using the WHO "building blocks" conceptual framework to structure the analysis (WHO, 2007). We discuss how different components of EPs became integrated into health systems (e.g. dengue, malaria, polio); and ways programs built assets for the ongoing management of health systems, including for disease control; finally, we evaluate the role of technology in eradication programs, and their sustained impact on health systems.

2 | METHODS

Research for this paper was based on two phases of literature review covering primary and secondary literature on the six major EPs from the 20th century. Initial literature review focused on a set of key resources for each EP, including program and strategy documents published by the commissioning body, such as WHO documents describing the organizational and strategic components of the EP, and its results. In reviewing key resources about each EP we aimed to identify program impacts on any of the six building blocks of health systems (WHO 2007), including: health service delivery; health workforce; health information systems; access to essential medicines; health systems financing; and leadership and governance. Further literature review was based on Boolean keyword searches on PubMed pairing the "name of the EP" or "disease" and one of the "building blocks", e.g. "smallpox eradication" and "health service delivery". If search terms returned fewer than 10 results, authors adjusted search terms by omitting the word 'eradication' to yield more results. For all searches, authors reviewed the list of results manually to ensure only relevant resources were included.

Limitations: This historical study is limited by the available English-language literature, and a potential bias in the authorship of the primary and secondary literature. The majority of the relevant literature about EPs is authored by the sponsors, leaders, and proponents of EPs, and therefore is likely to tilt in favor of the positive impacts of these programs on health systems. Critical perspectives are offered in the literature on the more recent EPs, and we have highlighted these in the paper as relevant.

3 | FINDINGS: IMPACTS OF EPS ON WHO'S BUILDING BLOCKS

We identified several ways EPs have influenced the building blocks of health systems, including five of the six WHO building blocks: 1) health service delivery; 2) health workforce; 3) health information systems; 4) leadership and governance; 5) medical products, vaccines and other technologies. In contrast, we did not find lasting legacies of EPs on a sixth building block, health system financing, beyond the financing for EPs themselves.

3.1 Service Delivery

Eradication programs could improve service delivery, particularly by building more robust immunization programs integrated within a country's health structure, increasing service coverage in rural areas and conflict zones, becoming an entrypoint for other health services, and providing health education.

Immunization: EPs have been integrated with existing health services, including for routine immunization. The smallpox EP integrated immunization for the disease into the health system (Okwo-Bele & Cherian, 2011). While early vaccine campaigns had deployed mobile teams for immunization services, after the EP was established in the mid-1970s, smallpox immunization services were built into routine services in health facilities (Okwo-Bele & Cherian, 2011). The yaws EP also integrated immunization with several related case finding and treatment activities, in addition to integrating with vaccination services for smallpox, yellow fever, measles, tetanus, and childhood tuberculosis. WHO (1965) reported the overall mass immunization campaigns against yaws helped stimulate an interest in and integration with rural health services. Health administrators in the Pacific Islands and Nigeria used the community's increased interest in health to promote rural health services. With decreasing yaws incidence in endemic areas, field teams also contributed to other initiatives such as vaccinations against smallpox (such as in Cambodia, Thailand, Nigeria and Haiti), cholera and typhoid (Thailand), leprosy case finding (the British Solomon Islands, Malaya, Togo, Indonesia and Nigeria; diagnosis in Thailand) and conjunctivitis treatments (Thailand).

Coverage in rural areas and conflict zones: EPs could also increase the reach of health services to low-resource settings, remote regions (Meheus & Antal, 1992) and conflict areas (Callahan et al.,

2013). For example, the malaria EP expanded coverage of health services in several rural areas, including throughout regions in Asia. Since these regions were difficult to reach the EP faced challenges, for example, navigating difficult terrain in Nepal, resistance to spraying, navigating conflict, and managing cross-border movement, including between India and Nepal; as well as across Thailand, Myanmar and Cambodia (Mills et al., 2008).

The hookworm EP paved new paths for public health initiatives by extending the reach of public health programs to rural populations, previously unreached, and expanding the scope and capacities of regional health departments, which became proficient in community-wide testing and treatment campaigns (Elman et al., 2014). Beginning in the early part of the 20th century, the hookworm EP operated across 10 US states, working out of mobile dispensaries, where staff tested people for hookworm infections and offered treatment with drugs. The staff would register the entire population, which sometimes consisted of several hundred people, test each individual for worms, persuade infected people to take multiple doses of thymol, which had severe side effects, and monitor the rate of infection. The staff also spent significant energy on public education about hygiene, including to navigate taboos associated with taking fecal samples. However at the end of 1914, the Commission recognized that mobile dispensaries did not prove effective (Elman et al., 2014).

Expanding coverage was also necessary in the case of yaws and GWD as these outbreaks were mainly found in rural areas, beyond the reach of existing health systems (Meheus & Antal, 1992). Beginning in the 1920s and continuing through the 1930s, initiatives to identify and treat yaws cases were conducted by mobile units and made a significant impact on the epidemic in regions in Central Africa. Following on this success, rural dispensaries were established to continue to expand coverage. Thus, the EP was an important starting point for the provision of basic health services in the area (Rapport de l' Administration belge du Ruanda-Urundi, 1938; cited in: Van Nitsen, R. 1946; WHO 1965).

In more recent years the GWD program helped bring health services to people living in conflict zones (Callahan et al., 2013), for example in Sudan where GWD intervention activities helped improve other health services in the region, including by supplying treatments for other diseases (Hopkins, 1998). In 1995, there was a 6-month "guinea-worm ceasefire" that provided an opportunity to deliver health services for GWD, in addition to related services for "over 100,000 persons at risk of onchocerciasis, to vaccinate over 41,000 children against measles, 35,000 against poliomyelitis, and 22,000 against tuberculosis, and to distribute more than 35,000 doses of vitamin A and treat 9,000 children with oral rehydration packets" (WHO, 1997).

Health education was provided in several EPs, however the role of health education in specific programs varied. Directors of the GWD eradication programs in Ghana, Nigeria and Pakistan found

that providing health education was a necessary first step (Hopkins & Ruiz-Tiben, 1991). Over the previous decade they had managed several national and regional eradication initiatives, during which they had learned health education was more cost-effective than other interventions. It also provided helpful grounding for other interventions, including the provision of rural water supply and vector control measures undertaken within the eradication initiative (Hopkins & Ruiz-Tiben, 1991). The directors of the GWD EP also expected that activating health workers and communities in these ways would have positive long-term benefits beyond eradication itself. Thus, health education was offered primarily by training village-based workers who supplied information to their neighbors and communities.

3.2 Health Workforce

EPs engaged and helped develop the health workforce in several ways, including by employing and training new workers at the community- and village-level, and engaging the existing workforce within national and regional health systems. However, the ways EPs affected the health workforce varied in significant ways both across and within individual programs. Also, the role of community- and village-level workers in past EPs has often been unacknowledged, and underappreciated. The smallpox EP showed that exchange of ideas between local and international workers was crucial to program success (Fenner et al., 1988: 515). In contrast, in other EPs that did not dialogue with horizontal systems, the local workforce felt alienated and this led to significant challenges in program implementation and improvement, including effectively utilizing and retaining health workers (Nájera, 2001).

Community and village: EPs trained community health workers and volunteers to expand the reach of programs and improve the delivery of eradication-related services (Fenner et al., 1988; Hopkins & Ruiz-Tiben, 1991). However, EPs differed in their intentions to develop these workers into a sustaining element of the workforce, as examples of the GWD and malaria EPs demonstrate. According to the leaders of the GWD EP, they considered building a workforce at the village-level to be a crucial element of the program strategy. In their writings, they recognized that additional workers could facilitate health education in the context of the EP and later be integrated into the primary health care program (Hopkins & Ruiz-Tiben, 1991). Thus, the GWD EP included significant initiatives to identify, train, and supervise village workers.

In the malaria EP, village-level volunteers (or "voluntary collaborators") were also trained to expand the reach of the program. However the quality of engagement with volunteers and management was limited, and their performance was primarily evaluated on their ability to assist with diagnosis, including in the production of blood slides, so their "coverage and productivity" varied greatly

(Nájera, 2001). These collaborators were considered to be on the periphery of the program, and therefore not given resources or training to become an enduring community health workforce.

National and regional: EPs also engaged the existing health workforce in countries and regions where they operated. In addition to training community and village-level workers, the GWP EP aimed "to mobilize and support otherwise underutilized members of existing health services at national, regional, and subregional levels" (Hopkins, 1998). However, programs tended to hire far more health service workers, including immunization teams, rather than senior staff.

The smallpox EP engaged existing national health staff who were otherwise undertrained and underutilised (Fenner et al., 1988: 515). Existing health personnel were given specialized training to become integral members of the mass vaccination initiatives (Fenner et al., 1988: 485). Over 700 international staff and 200,000 national staff were engaged in the global smallpox EP (WHO, 1980). More than 700 epidemiologists from 70 countries are believed to have participated in the program as international personnel (Arita, 1980). This training and workforce development was understood to be necessary to support the aims of the EP, in part, because the existing healthcare structures did not have adequate capacity to achieve eradication (Fenner et al., 1988: 1352). The "exchange of ideas" between international workers and local Indian and Bangladeshi staff was also crucial for the effectiveness of the smallpox EP. In places where the WHO and UN field staff were willing to communicate with and listen to the junior local staff, it helped create useful feedback loops (Bhattacharya & Dasgupta, 2009).

However, in the smallpox EP there were an insufficient number of professional staff dedicated to the program, both at the WHO headquarters and in national programs (Fenner et al., 1988). While the program engaged large numbers of vaccinators, there was a reluctance to hire senior management positions. This created many obstacles for the program, including by limiting its ability to disseminate public information, generate voluntary contributions from donors, and coordinate across national programs. Lack of senior staff also impeded the efficiency of national case management systems, and comprised quality control for vaccine manufacturing and delivering health education (Fenner et al., 1988).

In the malaria EP, human resources were brought in from the existing Ministry of Health, "the malaria eradication program and state and municipal health services" (Hochman, 2009). Instead of putting in a "vertical and centralized model" Brazil managed to have a flexible decentralized structure where it used existing resources and allowed states more control over their staff (Hochman, 2009). There were also notable tensions between the existing workforce and personnel included in the global malaria EP. Since the program did not modify its strategy to adapt to national contexts, the established knowledge and practices of experienced malariologists were sidelined, as young

trainees from the WHO's "Malaria Eradication Training Centres" were prioritized (Nájera et al., 2011). This presented short- and long-term issues for human resource management. In addition to crowding in new personnel to replace existing staff, the EP also faced challenges in retaining workers because expertise in malaria was not considered to be an attractive career choice (Nájera et al., 2011).

3.3 Health Information Systems

EPs demonstrated they could build more robust health information systems, primarily through the establishment of national and regional disease surveillance systems, and by refining practices for measuring the impact of population-level interventions. Given the centrality of information systems to ongoing success of eradication and control, leaders of the smallpox EP also contended that training for surveillance activities should include broader skills that would further strengthen health systems. Experience from past EPs shows that building more robust information systems benefited from refining methods to adapt to local surveillance and reporting practices. The smallpox EP, for example, adapted methods to fit within country contexts, and drew support from local community groups to identify cases and trace contacts. In contrast, the malaria EP was not as adaptive, and encountered challenges.

Surveillance activities: Disease surveillance has been a crucial component of many eradication initiatives, beginning with the smallpox program (Fenner et al., 1988). Some EPs established the first surveillance systems in the regions where they operated, for example, in regions affected by yellow fever in the middle of the 20th century, there were no information systems available when the EP began and therefore, the programs designed and deployed new systems of surveying, mapping and monitoring cases (Soper, 1965). However, not all eradication initiatives implemented surveillance systems, and some took a significant amount of time to establish these systems, including the yaws campaign, which took 10 years to establish a surveillance program (Henderson, 1998).

The ability of EPs to construct and use surveillance systems varied by the disease program and the country of operations. There were successes. For example, through persistent reporting and surveillance activities, EPs for GWD and smallpox led to significant improvements in national health information systems (Fenner et al., 1988; Hopkins & Ruiz-Tiben, 1991). EPs also developed surveillance activities through the implementation and use of national surveys (Hopkins & Ruiz-Tiben, 1991), GIS technology (Cairncross et al., 2002), and mapping (Nájera, 2001). Community health workers have also played an important role in improving surveillance and continuous reporting (Callahan et al., 2013; Fenner et al., 1988; Hopkins & Ruiz-Tiben, 1991).

To support surveillance activities, the GWD EP mobilized community members to conduct national surveys, and reported findings through the national health systems. By conducting national surveys for active cases, the program greatly improved on the existing reporting and provided a more accurate status of the epidemic. However, since the workers were not present in all villages, the data was not complete, and there were challenges assimilating this data within existing national health systems (Cairncross et al., 2002). The GWD EP was also the first program to use GIS technology extensively, and this EP expanded its use of technical capacities through databases and softwares for a range of purposes (Cairncross et al., 2002). The GWD surveillance system has also been used for reporting of other diseases (such as tetanus, lymphatic filariasis, and leprosy) in Ghana and Nigeria (Muller, 2005).

The malaria EP encountered challenges with the implementation of surveillance systems, which some observers attributed to the available health infrastructure in respective countries; however definitions from the Expert Committee were also said to be too vague and poorly adapted to the local needs. In some countries, surveillance systems for malaria incidence were constructed and maintained. For example, Sri Lanka was regarded as a model case. However, even in Sri Lanka, the surveillance systems developed weaknesses which allowed for a resurgence of malaria in the late 1960's (Nájera et al., 2011).

The smallpox EP highlighted the need for high-quality surveillance, as a long-term sustainable approach to disease monitoring and control (Okwo-Bele & Cherian, 2011). In fact, the smallpox EP was characterised by its emphasis on surveillance, which eventually was instrumental in achieving eradication. This was crucial because in many health systems where the EP operated, only very limited surveillance systems existed previously (Fenner et al., 1988: 473). Surveillance was a major challenge for Brazil during the smallpox EP (Hochman, 2009). To overcome this, Epidemiological Surveillance Units were created with the help of PAHO/WHO, which were eventually present in every state, managed individually by them. "These represented the embryo of the National Epidemiological Surveillance System (Sistema Nacional de Vigilância Epidemiológica) established formally in 1975" (Hochman, 2009). When the surveillance components were established, they were designed in line with principles of health system strengthening.

The leaders of the smallpox EP contended surveillance and training should cover broader skills and basic concepts because they were also key to PHC and general health systems, and the existing systems in most endemic countries were very weak (Fenner et al., 1988: 475). The WHO Director-General emphasised that surveillance systems must be put in place even where local health structures are weak. The EPs presented an opportunity not only to address a target disease, but also to improve local systems. Thus, the Director-General asserted surveillance systems being developed for the EP should also 'provide epidemiological services for other communicable diseases'

(Fenner et al., 1988: 410–11). According to Fenner, the smallpox EP improved supervision, and regularised reporting, including by introducing incentives. Assessments conducted at later stages of the EP were also extended to collecting data on other diseases and on the availability of general health services Fenner et al., 1988: 506).

In some cases the surveillance activities of EPs were expanded to include information on other health services (Fenner et al., 1988). For instance, in Bangladesh surveillance teams captured information on rural health centres, contraception (use of contraceptive pills, and public awareness of family planning), and water wells used to support irrigation and sanitation (Joarder et al., 1980). In other areas, surveillance teams gathered incidence and prevalence data for measles, tetanus, poliomyelitis and blindness (Fenner et al., 1988). Similarly, the yaws EP also took an integrated approach to surveillance in some areas (WHO, 1965). For example, in Java surveillance was managed through rural health dispensaries; in Thailand, surveillance was integrated with rural health services; in the Philippines, the yaws campaign was part of the public health structures. However, in other areas of the Americas and Africa, this was not possible, due to the lack of rural health services.

Coverage: Many EPs aimed to expand coverage of existing health information systems, and some found success, however this proved very difficult to achieve. The GWD EP surveillance activities were supported by reward schemes, multimedia broadcasting, and integration with other large-scale programs (Biswas et al., 2013). These activities helped expand outreach to affected villages that were previously not covered by other monitoring and reporting systems (Hopkins & Ruiz-Tiben, 1991). To expand surveillance coverage, the malaria EP promoted the use of maps, including 'locality sketch maps' containing details of house locations, communication means and census information. At the time, this became the best available information source in some countries. These maps were reportedly used in the smallpox campaign, however they were later neglected (Nájera et al., 2011). The surveillance system required support from a strong laboratory network, logistics and capacity. In the absence of these, the surveillance workers and even the laboratories were overworked. Eventually, the surveillance systems were incapable of detecting resurgences in time for response (Nájera et al., 2011).

3.4 Leadership and Governance

EPs could impact the leadership and governance of HS, including by facilitating cross-sector collaboration, and establishing cooperative relationships with related development programs, including for water sanitation. However, EPs encountered challenges with leadership, including lack of political interest, especially after making an impact on disease trajectories. The inability to sustain political will to support the ongoing management of programs, and the health sector more generally,

has been cited as a reason for failure. In the case of the dengue EP, for example, when the disease vector was eliminated from specific regions for periods of time, political interest waned, and the program was challenged to maintain previous levels of disease control.

Collaboration (cross-sector; development): EPs could facilitate cross-sectoral collaboration, and establish cooperative relationships with related development programs, including for water sanitation. The hookworm EP introduced a new approach to the management of public health programs, which required '(re)alignment and engagement' with a broad range of stakeholders, including clinicians, public health departments, politicians, corporations, media, and the general public (Elman et al., 2014). These coalitions stitched together the interests and activities of the UN organizations, bilateral assistance agencies, private sector, NGOs, national and political leaders. Hopkins (1998) credits the creation and management of broad multi-stakeholder coalitions for the success of GWD EP. The hookworm EP also collaborated with WASH activities, with evidence of success in the US and Japan (Strunz et al., 2014).

A cooperative relationship with the UN water sanitation initiative also helped launch the GWD EP (Stepan, 2019: 242), and even after the UN initiative concluded, the GWD EP extended its operations through national and international agencies, and continued to dig wells in endemic villages, such as throughout south-east Nigeria. Like the activities of the UN initiative, the GWD EP realized the double-benefit of providing access to clean-drinking water and effectively eliminating GWD infections (Hopkins, 1998).

Political interest: Sustaining political interest in eradication activities has been a challenge. In the case of the dengue EP, when the disease vector was eliminated from specific regions for periods of time, political interest waned. This lack of political will to support the ongoing management of programs, and the health sector more generally, has been cited as a reason for the program's failure (PAHO, 1997). Programs attempted to generate sustained support from international donors. For example, the GWD EP hosted regional conferences and presentations highlighting the accomplishments and challenges of national coordinators (Cairncross et al., 2002). Their success in sparking or sustaining international support varied. The yaws EP was stalled, some have argued, because it was never supported by a WHA resolution (Keegan et al., 2011).

Strategy development: While some EPs developed program strategies that were agile and responsive to national contexts, others were based on rigid templates. For instance, there was considerable resistance from the Indian government in implementing the smallpox EP (Bhattacharya & Dasgupta, 2009). The EP only started gaining support after the WHO officials were more inclined to undertake discussions with the local authorities and realised that a top-down approach from officials based in Geneva would not be effective. While the WHO facilitated and advocated for adop-

tion of strategies based on best practices, the smallpox eradication program was eventually tailored to fit within existing strategies and programs within countries (Cohen, 2019). Team leaders were also encouraged to actively spend more time in the field to help solve the problems faced by field workers. This proved important in ensuring quality of surveillance, monitoring, and reporting (Cohen, 2019). Moreover, they were actively asked to hire local staff who were treated as "valued partners" and helped develop policies that fit the social and political context (Bhattacharya & Dasgupta, 2009). In contrast, the yaws EP "did not adjust strategies to effectively address surveillance problems and the difficulties of eradication in latent cases of disease" (Keegan et al., 2011), and for similar reasons, the malaria EP "faced numerous obstacles in strategy development, supplies, and logistics and allowed research to lag behind program needs" (Keegan et al., 2011). Similarly, Soper was known to focus on 'rigorous public health administration' rather than the disease epidemiology and this strategy carried forward to the campaigns he led against Aedes aegypti (Stepan, 2019).

Building knowledge on effective strategies: Knowledge gained from EPs have also influenced national disease control programs, and more general health management needs. At the same time as the yaws EP was operating, several related yaws control programs supported related disease control techniques, including case finding for related diseases, including leprosy, African sleeping sickness, and maternal venereal syphilis; in addition to vaccination against smallpox, yellow fever, measles, tetanus, and childhood tuberculosis (Hopkins, 1985). Following the end of the yaws EP, India started its own national campaign in 1996. The strategies of that campaign are adopted from the global campaign. Since 2004, India has not reported any cases of yaws. Following this success, WHO also set elimination targets for Indonesia and Timor-Leste (WHO, 2008). Management principles from the smallpox EP were used for other health programs as they were introduced into national and community-based initiatives (Fenner et al., 1988: 1369).

Example-setting: Global eradication programs set important examples for each other as well as for national disease eradication programs. The early hookworm EP undertaken by the Sanitary Commission is said to have created a "model for international efforts in public health for over forty years" (Birn, 1996). The malaria EP influenced "Mexico's commitment to modern public health organization and methods" – even though the EP did not operate in Mexico, the Mexican government's national campaign was influenced by the EP's operations and strategies (Birn, 1998). The success of the smallpox EP also provided a push for new initiatives in "immunization, diarrhoea disease control and the prevention of blindness" (Fenner et al., 1988).

3.5 Medical Products, Vaccines and Other Technologies

EPs could also facilitate improved access to medicines, including by strengthening national and global supply chains; establishing quality assurance processes; and in some cases supporting local production of vaccines.

The development and deployment of medical products and technologies has been an integral activity in eradication programs. A wide variety of technologies were used in the EPs, including: cloth filters to help treat water where the guinea worm was present; testing stool samples to detect cases of hookworm; insecticides to kill mosquito larvae and fumigate buildings (malaria, yellow fever); long-acting penicillin to treat yaws; and improved injection devices to administer the smallpox vaccine. EPs usually selected low-cost options that could be made widely available, including in remote areas. In some cases, they had to overcome logistical challenges for administering these technologies, including by building or modifying efficient supply chains and local production capacity.

The smallpox EP also continually improved on vaccine production and quality assurance through the provision of manuals for production, and by assisting with establishment and management of local manufacturing, as well as batch testing for improvements in vaccine quality (Cohen, 2019; Fenner et al., 1988). The smallpox EP was also supported by WHO, which expanded its role from technical to operational coordination during the program to overcome the logistical and administrative challenges that created bottlenecks at national levels, such as for local funding, transport and global supply chains (Cohen, 2019; Fenner et al., 1988). WHO's operational role helped strengthen supply chain logistics including by moving supplies and equipment between countries as needed, creating emergency reserves of vaccine and vaccination instruments, and managing special funds for urgent equipment requirements or for special consultants (Henderson, 1987). During the smallpox immunisation campaigns in Brazil, PAHO/WHO also helped modernise national vaccine manufacturing capacities and increase production volumes, including by assisting the government in building laboratories that could produce the freeze-dried vaccine (Hochman, 2009).

The supply chain infrastructure erected by the GWD EP also became an important link in the distribution of other drugs and medical products. As of 2015, this network had distributed over 100 million doses of ivermectin to prevent river blindness; supplied insecticide treated bed nets to families with a child under the age of five during measles vaccination campaigns; and distributed antibiotics for the treatment of trachoma (Hopkins et al., 2008).

3.6 Financing

Of the six building blocks, we found the least evidence that EPs left legacies for the financing capacities of health systems. Perhaps because eradication efforts were to be, by nature, time-limited, establishing sustainable financing was not a priority. We found that eradication programs have been financed by a range of sources spanning domestic, international, and philanthropic organizations. However the source of funding and size of the budget has varied across programs, and detailed information was difficult to find.

In terms of overall budget size, the programs varied widely. The smallpox EP was supported by a combination of endemic and donor governments, which contributed approximately $300 million over the life of the program (Keegan et al., 2011). Other EPs cost less: the GWD budget was near $250 million, and yaws budget was only $9 million. Meanwhile, budgets for malaria (and polio) grew to several billions of dollars (Keegan et al., 2011).

In terms of sources, philanthropies dedicated significant amounts of money to EPs, and have played a significant role in funding EP for at least a century. For example, between 1925 and the late 1930s, the Rockefeller Foundation dedicated over half of its overseas health budget to the yellow fever EP (Stepan, 2019).

EPs also drew substantial support from international organizations, development initiatives, and in some cases, the health budgets of national governments. The GWD EP first sourced funding from the UN's International Drinking Water and Sanitation Decade (1981–1990), and received support from the CDC, UNICEF, WHO and BASF through financial, technical training and logistical support (Awofeso, 2013). In the 1950s and 1960s one-third of WHO's financial and technical resources were dedicated to the malaria EP (Stepan, 2019:194), which comprised a sizable portion of the overall health budget in some countries where it operated. In India, support for the malaria EP required one-third of the total health budget, while in Nepal it was nearly one-fourth of the ministry's total expenditure (Mills et al., 2008: 6–7). In contrast, PAHO's annual budget of $1.5 million remained insufficient for providing adequate support to each of the different national programs in Latin America. Indeed, national governments spent large portions of their health budget on their malaria eradication commitments.

While EPs themselves have attracted large amounts of resources, they do not seem to have changed or necessarily strengthened the way health systems are financed more broadly. A better understanding of how financial resources have flowed through EPs – through health systems or alongside them, and what implications this has for sustainability – is an important area for further research.

3.7 Beyond the Building Blocks

The WHO 'Building Blocks' offer a helpful framework for understanding the different ways EPs impacted national health systems. However, we also found that the influence of EPs reached beyond the building blocks, including by growing community networks, and extending across national borders. EPs involved an array of actors, and developed several local and inter-regional collaborations.

Community networks: Hopkins and colleagues at The Carter Center, who spearheaded the GWD EP, contend their legacy lives on in networks of community-based services, which they helped build and which have been strengthened to address other NTDs, including in several rural regions of sub-Saharan Africa (Stepan, 2019). In contrast, village-level volunteers in the malaria EP were considered to be on the periphery of the program, and primarily engaged to assist with diagnostic activities (Nájera, 2001; Nájera et al., 2011). In the GWD EP community mobilisation had positive impacts including through support of preventive measures, and the provision of health education (Stepan, 2019). Since the strength of the network was vital to achieving the goal of eradication, and the network laid an infrastructure for future eradication initiatives, the leaders of the GWD EP have argued for the importance of community mobilisation for public health. They contend the community networks are important legacies of the EP.

Gender Equity: EPs have been credited for advancing health equity, including by increasing access to services, and broadening the aim of programs to more adequately include women as health service providers. As part of the GWD EP, women in sub-Saharan Africa were trained to provide health education, conduct disease surveillance, and protect water sources from contamination (Callahan et al., 2013). Thus, leaders of the GWD EP suggested the program played a role in advancing women's role in the provision of healthcare. However, analysts of other EPs have also identified ways interventions may have reinforced gender roles, including by representing stereotypical images of men and women in health education campaigns, or by only including women in gendered forms of service delivery, including as nurses or midwives (Birn, 1999).

Intergovernmental and regional collaboration: The support of PAHO was important to facilitate cross-border collaboration and build regional (not just national) initiatives, including in Brazil, the Caribbean, and other regions of Latin America. EPs also provided models for intergovernmental strategies that were taken up by PAHO. While the initial *Ae. aegypti* eradication program (1947–70) was not successful, it strengthened inter-regional collaboration in the Americas and provided the basis for a governance structure for PAHO's strategy to eradicate dengue in the 21st century (PAHO, 2018). Following the example of the previous EP, and in response to emergent outbreaks, PAHO adopted an Integrated Management Strategy for Dengue Prevention and Control (IMS-dengue) (PAHO, 2018).

In addition, the success of the smallpox EP had a far-reaching impact on international-health strategies (Packard, 2016), including by fostering multilateral support for health initiatives, and offering important lessons about the potential use of medical technologies. The smallpox EP also showed that impact was achievable through vertical approaches; however it also raised concerns about the potential negative impacts of inflexible programs on weak health systems in low-resource settings.

4 | DISCUSSION

EPs have influenced the development of health systems in many different ways. The evidence presented above illustrates the many ways in which EPs can leave beneficial legacies for health systems, but it does not mean they always or necessarily do. Rather, there have been significant variations in how intentional or strategic these programs were in their interactions with health systems, either in the initial planning stages, throughout the operating timeline, or in the transition toward disease control. These variable experiences with integration may also be instructive for ongoing strategies for disease eradication and control.

4.1 Intention and timing of integration

We found similar trends in past EPs, for which integration was not the goal initially. While in select EPs disease surveillance systems were integrated from the outset and managed by national programs, more often, integration was initiated after programs matured and the ongoing management of operations became a key area of concern. Specific components of EPs have been integrated into national health systems during different stages of operations, and in several cases, integration focused on program components supporting health services and health information systems. Under pressure of failure and financing, leaders of EPs learned interventions could have more long-term impact if they were integrated into broader health systems, and/or coordinated across borders (e.g. dengue), and therefore required better integration through regional systems of governance. EPs also encountered significant variations across different countries in which they operated, which affected their intent and ability to integrate (e.g. malaria, yaws).

In the dengue EP, surveillance activities were integrated at different stages of the program, however the most comprehensive integration activities were initiated after the program encountered significant challenges. In the early years of this program, surveillance was managed by Brazilian national programs, and the scope of these national surveys was impressive. However the national programs were challenged to keep pace with the evolving epidemic, including to follow vectors across borders. As the surveillance programs matured, health officials recognized an "urgent need for a unified health system capable of generating essential epidemiological surveillance information" (Serufo et al., 1993). Brazilian government agencies recognized that integrated efforts within

neighboring states and countries would be essential to avoid disease resurgence, and therefore consistent regional government measures would be required (Halstead, 1980; Tauil, 1986). Therefore, effectively integrating the EP and sustaining disease control would require significant work beyond interfacing with the individual health system, including the development of new regional regulations to better facilitate the relationship between the EP and multiple health systems.

The GWD EP has been recognized for integrating with health services and health information systems in several countries. However, there was debate about whether to integrate these activities within national systems (Cairncross et al., 2002), and the interactions between the EP and national health services varied based on the existing capacities of any individual country's health systems. In all countries, the EP worked "within or in close liaison with the healthcare system. In most endemic countries, the program was operated with the national level providing overall strategic guidance, regular monitoring and evaluation, whereas all interventions were implemented and managed by the primary healthcare system with its outreach services under the supervision of the district and state (provincial or regional) administration" (Biswas et al., 2013). Conversely, the limited capacities in some countries, also affected the implementation and operations of the EP.

In the smallpox EP, a partially integrated model was implemented. Henderson supported mass vaccination campaigns that were linked to health services. However, he argued that fully integrated programs would suffer due to lack of clear structures and strategies while a dedicated approach would allow better mobilisation of funding and resources (Cohen, 2019). Under this partially integrated model, several administrative and operational components of the program were integrated and adapted to national context, including by appointing national staff to positions of leadership, in collaboration with WHO staff (Fenner et al., 1988: 1361). As a result, "smallpox teams were not required to set up fully parallel surveillance systems, instead augmenting existing ones and leaving behind some added capacity within health programs" (Cohen, 2019). However, the smallpox program was not built to respond to more visible and urgent health issues in the regions where it operated (Cohen, 2019). For instance, during the cholera epidemic in Bangladesh, smallpox vaccinators provided the community no assistance for the response to this emergent threat. As a result, they were critiqued and met with resistance by communities. Learning from this experience, the smallpox EP made it the responsibility of surveillance teams to better engage with the community, especially when case incidence was low, including by conducting surveys on other health-related issues, such as "clean water, vitamin A, family planning, and rates of childhood mortality" (Cohen, 2019).

4.2 Challenges with integration

Some leaders of EPs were resistant to integration out of concern that the aims and components of EPs would be lost within weak health systems. Making concerns worse, some programs exposed the limits of health information systems when they were initiated in many countries (Fenner et al., 1988; Hopkins & Ruiz-Tiben, 1991). Information systems for surveillance and reporting were either entirely missing (Fenner et al., 1988; Soper, 1965), had underdeveloped structures (Fenner et al., 1988) or did not reach significant parts of the population, including those in rural areas (Hopkins & Ruiz-Tiben, 1991). The EPs also exposed limitations of existing service delivery resources (Fenner et al., 1988) and laboratory capacities (Nájera, 2001).

Concerns about the limitations of existing health system capacities influenced different approaches to integration. The leaders of the smallpox EP contended surveillance and training should cover broader skills and basic concepts because they were also key to PHC and general health systems, and the existing systems in most endemic countries were very weak (Fenner et al., 1988: 475). The WHO Director-General emphasised that surveillance systems must be put in place even where local health structures are weak. The EPs presented an opportunity not only to address a target disease, but also to improve local systems. Thus, the Director-General asserted surveillance systems being developed for the EP should also 'provide epidemiological services for other communicable diseases' (Fenner et al., 1988: 410–11).

EPs also encountered significant variations across different countries in which they operated, which affected integration. Initially the malaria eradication programs operated as "autonomous structures" that were independent of health systems and not well adapted to local contexts (Nájera et al., 2011). However, when the program suffered from funding and preparedness issues, the strategy was later revised to include prerequisites for integration to better ensure program feasibility (Nájera, 2001). In the case of the yaws EP, WHO emphasised the need for integration of eradication activities into public health services in order to use the mass programs as an impetus for improving general health services (Stepan, 2019). However, since health services were underdeveloped in many endemic countries, premature integration of the treponematoses control program (TCP) into national primary health care systems led to the decline of commitment and resources of the program before cases (of yaws or other treponematoses) were successfully eliminated (Cochi, 1998; Rinaldi, 2008; Marks et al., 2015). Indeed, the process of integration has not always benefited the health system nor the eradication programs, and lessons from some programs suggested integration required a level of readiness.

4.3 Supporting health systems for disease control

In the process of erecting health services and information systems adequate to keep pace with multi-dimensional epidemics, eradication programs built a set of techniques for managing disease control. While there were substantive differences in the intentions of programs to integrate during different stages of their operations, ultimately many assets of eradication programs became integrated into national health systems, as the programs were transitioned into disease control initiatives. In this way, the eradication programs provided a foundation for national disease control strategies.

As the smallpox initiative worked to meet the needs for high quality surveillance, its champions began crafting methods for a long-term sustainable approach to disease monitoring and control (Okwo-Bele & Cherian, 2011). Techniques for disease control included case finding, contact tracing, and mass communication campaigns to inform affected populations, and ring vaccination, many of which were used for containing guinea worm (Richards et al., 2011) and Ebola (WHO, 2020).
The knowledge, methods, and workforce developed during the hookworm EP were also taken up in future control strategies. This program offered a template for conducting population surveys, mapping districts, managing personnel, and leading inspections, which could be applied to future campaigns (Stepan, 2019). Trained, motivated mobile teams from the program continued to lead in the control of other epidemic diseases such as smallpox, yellow fever, and meningococcal meningitis (Cochi et al., 1998).

The yellow fever EP improved the management capacity of national health systems to administer disease control initiatives. In Brazil, yellow fever eradication efforts preceded the Continental Eradication Plan and were operated through an autonomous Yellow Fever Service. As the 'only organised administrative health service in the region' at the time (Soper 1965), the Yellow Fever Service was a helpful model on which to build a new malaria service – North East Malaria Service (NEMS) (Stepan, 2019), equipped with lessons learned, management principles and workers from the Yellow Fever Service. However, both services were set up autonomously and were independent of other public health activities (Stepan, 2019).

Based on the lessons from the malaria EP, the malaria control strategy also emphasised that diagnostic and treatment facilities for malaria should be part of the health infrastructure and that they should allow for later development of primary health care (Nájera, 2001). However, malaria control activities further exposed limitations in laboratory capacities (Birx et al., 2009; Hailegiorgis et al., 2010; Ishengoma et al., 2010), and the general lack of readiness in health facilities (Lee et al., 2017).

4.4 The role of technologies in EPs

A range of health technologies have been deployed in eradication programs, and given the general tendency to deploy technologies to treat disease, EPs have been critiqued for being overly biomedical or vertically-oriented. In some cases, EPs were also criticized for using products with dangerous side effects. We found the role of technologies varied significantly across different programs.

In the worst case scenario, technologies were not proven to be safe and could do serious harm. For example, analysts have identified significant issues with the use of treatments in the hookworm EP. Chemicals known to have mild to severe side effects were used in different phases of the EP, including during the initial campaign in the Southern United States where thymol was used (Stepan, 2019). Later, the Rockefeller Foundation's International Health Board (IHB) transitioned to the use of chenopodium oil, which also had alarming side effects and in some cases, seems to have led to death in children (for full details, see: Palmer, 2010). It is unclear whether these experiences led to changes in the regulatory systems of countries where chenopodium oil was used, or in the Rockefeller Foundation's hookworm eradication strategy. This case starkly illustrates that technologies deployed by EPs could bring with them significant risks for populations.

EPs for mosquito-borne illnesses were also transformed and challenged by the use of toxic chemicals. The early years of the yellow fever EP were based on the 'inspection of containers and oiling of breeding-places' of mosquitoes, however as DDT became more widely available, the Continental Eradication Plan began using the low cost insecticide to target breeding sites and spray inside homes. Since DDT had known toxicities, EPs were criticized for using it (Stepan 2019), and eventually transitioned toward using more expensive and short-acting insecticides. Unfortunately, these alternative insecticides were not as readily available, so programs sometimes faced shortages in supplies, which stalled operations (Mills et al., 2008).

The ways technologies have been used in EPs also highlights the dynamism involved in implementing and using technologies to eradicate diseases. The availability of new and seemingly effective technology may have shaped some eradication programs (Henderson, 1998). As technologies have become available, the methods of disease eradication have shifted to respond. A low-cost and long-acting penicillin injection pen opened the possibility of mass treatments for yaws and smallpox. The effectiveness of the penicillin treatment provided an important impetus to the EPs. Even though the technology eventually proved not as helpful as first anticipated, it "stimulated the undertaking of mass vaccinations" (Fenner et al., 1988:406). Moreover, it had significant advantages over the techniques in use at the time. Pilot studies showed that a jet injector required a much smaller workforce and would cost one-third of the existing techniques.

However, not all EPs had treatments or other medical technologies available. Since there was, and continues to be, no available drug-based therapy for GWD, this program offered an alternative model for eradication based on health education. This approach was developed after several years of learning about the most cost-effective interventions, and the ability to take interventions to scale in different contexts. Initially, the program planned to build wells and use cloth filters to manage contaminated water (Hopkins & Ruiz-Tiben, 1991). However, after nearly a decade of managing regional GWD eradication initiatives in Pakistan, Ghana and Nigeria, the soon-to-be leaders of the GWD eradication initiative observed building wells in rural areas was costly and less effective than hoped for, because the wells were difficult to maintain, often not deep enough to be effective, and distant from where people lived. Based on these learnings and cost pressures, the GWD eradication program shifted toward health education programs, which proved effective. This approach also had the benefit of contributing to service delivery by mobilizing communities around public health, including by establishing a network of community-based health education volunteers across rural areas of Africa (Hopkins et al., 2008).

The hookworm EP was also critiqued for promoting a therapy-first approach to disease management, which prioritized testing and treatment over and above social-structural interventions (Packard, 2016). While it was recognized that structural factors, including lack of access to nutrition, sanitation and shoes drove disease prevalence, the campaigns did not focus on improving structural conditions. Instead interventions were designed primarily to 'test and treat' populations (Stepan, 2019). The ease of diagnosis and availability of a 'quick-fix treatment' may have influenced this more vertical orientation (Birn, 2014).

Overall, the role of technologies in EPs was neither uniform nor straightforward. In the worst cases they could cause significant harm, or displace more effective social interventions. But they could also expand the reach of health systems by making it feasible to reach rural areas (e.g. single dose long-acting penicillin, the smallpox jet injector). Furthermore, as technologies have become embedded within health systems, they have been adapted in response to observed effectiveness, and context of use. A co-evolution between the technology and health system can be observed, underscoring that they do not operate independently of each other.

5 | CONCLUSIONS

EPs left important legacies for health systems, across 5 of the 6 WHO building blocks. These legacies have varied by EP, by country, and over time. Leaving positive legacies is by no means automatic or guaranteed – agency and intention matter. The evidence shows that, despite the challenges that vertical disease-focused programs pose to health systems, productive legacies can be achieved.

All EPs ultimately had to address the question of integration, whether integration of assets post-eradication (smallpox) or integration into HS in order to continue activities. We found variation in when and how EPs integrated, and challenges – a few seemed successful whereas others were stymied. The success of some EPs sparked interest in integration, and by integrating, EPs led to the further development of health systems. However, concerns regarding capacities of health systems and willingness of national governments to support integration activities have been raised across several EPs.

EPs also missed opportunities to create more impactful legacies. This was a consequence of ad-hoc rather than strategic integration. EPs could have been leveraged to support broader reform initiatives, such as large-scale sanitation and hygiene programs, in the case of hookworm, or by more meaningfully engaging local workers, as in the case of smallpox or malaria. The observation that EPs did not make sustained impacts on HS financing is worth noting, and deserves further scrutiny. While our research did not include a forensic search for all aspects of HS financing, no primary literature nor historical analyses we reviewed offered evidence of strengthened HS financing as a legacy of EPs. Further research is needed to understand the ways financing for EPs flows through, or around, health systems.

For present and future EPs considering their potential legacies, it will be useful to be explicit about potential impacts on each of the six building blocks. Similarly, short/medium-term and longer-term impacts should be considered, not just on the day-to-day operations of health systems, but also on broader contributions to global health such as the development of knowledge, practices, or shared understandings of what is possible to achieve. It can also be useful to expand the concept of legacies beyond the national level, and look at an EP's impact at regional and international/global levels. However, unless integration strategies address the question of sustaining impacts on all building

blocks, including health system financing, their legacies may remain incomplete. Conversely, since health system financing continues to be one of the greatest challenges to global health, EPs may have an opportunity to advance their legacies through building sustainable approaches to health system financing.

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