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The Global Effort to Eradicate Rinderpest

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Notices

[1] Effective January 2007, the Discussion Paper series within each division and the Director General's Office of IFPRI were merged into one IFPRI–wide Discussion Paper series. The new series begins with number 00689, reflecting the prior publication of 688 discussion papers within the dispersed series. The earlier series are available on IFPRI's website at www.ifpri.org/pubs/otherpubs.htm#dp.

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The GREP, the final stage of the global rinderpest eradication initiative, was a concept conceived and developed by a relatively small number of farsighted people. The fact that it was successful owes much to the foresight and dedication of many, including those who made especially significant inputs into rinderpest control and eradication during the last 50 years: Yoshohiro Ozawa, Yves Cheneau, Walter Plowright, Gordon Scott, William Taylor, and Mark Rweyemamu merit special credit. Many others made particularly seminal contributions to the conduct of global rinderpest eradication and it would be remiss not to mention particularly the long-term commitment of, inter alia, Gijs van't Klooster, Jeffrey Mariner, Ahmed Mustaffa Hassan, Bryony Jones, Rafaqat Hussain Raja, Gholam Ali Kiani, Manzoor Hussain, Tim Leyland, Andy Catley, John Anderson, John Crowther, Roland Geiger, Martyn Jeggo, Berhanu Admassu, Paul Rossiter, Richard Kock, Dickens Chibeu, Tom Barrett, Adama Diallo, Mohammad Afzal, and Walter Masiga. Inevitably, this paper draws on some material used for various earlier publications that were prepared in collaboration with William Taylor and Mark Rweyemamu, and their collaboration is sincerely appreciated.

ABSTRACT

During the past 70 years, concerted efforts by the national veterinary services of affected countries from Senegal to China and Russia to South Africa—aided by international organizations—have brought the once-dreaded rinderpest virus to the point of extinction. In the near future, we can expect to see a global declaration of freedom from rinderpest, the first time this has been achieved for a livestock disease. The devastation wrought by rinderpest stimulated the founding of veterinary schools in many countries, and provided the basis for the development of the veterinary profession. The legacy of control programs in the past 20 years includes vaccine innovations and the development of new epidemiological and surveillance tools that are based on participatory techniques. Additionally, the benefits derived from eradication are many, ranging from increased confidence in livestock-based agriculture to increased food security, protected rural livelihoods, technically more proficient veterinary services, an opening of trade into lucrative markets in the Middle East, and the safeguarding of Africa's wildlife heritage from a serious threat to its dwindling populations. As for the financial benefits of rinderpest eradication, describing them is constrained because of a general lack of studies on the subject, and the fact that programs covering multiple issues often did not clearly discern the rinderpest problem. This analysis attempts to present lessons learned from the experience gained in eradicating rinderpest, and explores the socioeconomic gains made as a result.

Keywords: Millions Fed, Food Security, Rinderpest, Livestock, Cattle, Disease, Epidemic, GREP

1. INTRODUCTION

The Origins of Rinderpest, its Nature and its Demise

Rinderpest, or cattle plague as it was long called in English, was a disease of antiquity in Europe and Asia. In the early twentieth century, Australia and South America experienced rinderpest introductions from Asia within a few years of each other, but both invasions were effectively contained. In contrast, however, when the disease was introduced into eastern Africa at the end of the nineteenth century, it spread rapidly to engulf the whole continent.

Rinderpest is thought to have had its origins as far back as the domestication of cattle, which was occurring in Asia, probably in the region of the Indus River some 10,000 years ago (Diamond 1999, Possehl 1996). With a host range that covers domesticated ruminants and swine as well as many wild artiodactyls (most importantly bovids, deer, antelopes, giraffes, and pigs) its impact has been severe not only on farmed livestock but also on wildlife populations, most recently in Africa (Kock 2006) but also in Southeast Asia into the 1950s (Hudson 1960).

Related to the human measles virus, of which rinderpest was most likely the precursor, rinderpest is caused by one of what in recent years has been recognized as a group of closely related, yet distinct, morbilliviruses: rinderpest, peste des petits ruminants (PPR), measles, canine distemper, phocine distemper, and a cetacean morbillivirus are currently recognized (Barnard et al. 2006).

Rinderpest is a contagious disease characterized by necrosis and erosions throughout the digestive tract and, in its severest form it is capable of killing 95 percent or more of the animals it infects. Affected animals develop fever, discharges from the eyes and nose, erosions of the mucosa from mouth to anus, diarrhea, dysentery, and death. The enteric lesions cause rapid protein loss, weight loss and dehydration that, in fatal cases, results in death typically after 10 to 12 days. Animals that recover are debilitated and suffer a long convalescence. On the other hand, there is no carrier state; surviving exposure to wild strains and attenuated live vaccine viruses confers a sterile, lifelong immunity with continuously present antibodies to viral antigens. Its appearance is most marked in fully susceptible herds as when the virus is introduced to a formerly unaffected area; classical cattle plague is seen with high mortality as occurred last in 1994 in the valleys of the Northern Areas of Pakistan, where some 50,000 cattle and yaks died in a few months. In areas of endemic maintenance—constituting reservoirs of infection where animals frequently suffer invasion of infection—many animals will be protected either from earlier exposure or possibly vaccination, and thus morbidity and mortality rates can be low. In endemic areas, classically characterized by extensive pastoralism, mild strains of the virus have been described and these can be very difficult to detect clinically in cattle. However, mildness is not a fixed viral characteristic and such viruses periodically assume higher virulence in their host populations and when transferred into distant susceptible host populations where a high virus transmission rate is possible. Wild animals generally suffer acute clinical disease with high mortality.

Not for nothing did Scott and Provost (1992) describe rinderpest as "the most dreaded bovine plague known, belonging to a select group of notorious infectious diseases that have changed the course of history." They went on to say that "from its homeland around the Caspian Basin, rinderpest, century after century, swept west over and around Europe and east over and around Asia with every marauding army, causing the disaster, death, and devastation that preceded the fall of the Roman Empire, the conquest of Christian Europe by Charlemagne, the French Revolution, the impoverishment of Russia and the colonization of Africa." That devastation continued well into the twentieth century. The impact of the disease in earlier times can be imagined when considering to what extent communities were dependent on their ruminant livestock for draft power, milk, meat, skins, and manure, just as they still are in many developing countries. Yet it was not just the domesticated livestock and the people who depended on them that suffered; the blow that rinderpest delivered to African wildlife when it was introduced for the first time was so severe that its effects are noticeable even today in the distribution of some ruminant species and of the tse-tse flies that feed on them. Innumerable numbers of wild ungulates—buffaloes, giraffe, wild pigs, and antelopes—died. Rinderpest continued to cause serious wildlife losses throughout the twentieth century as is amply demonstrated by the “spring sickness” of wildebeest calves, which depressed their population in the Serengeti and Masai Mara in the 1960s (Taylor and Watson 1967) and the deaths of many thousands of African buffaloes—some 60 percent of the total population—as well as large numbers of eland, kudu, and giraffes in and around Tsavo National Park in Kenya during 1994–95 (Kock et al. 1999).

When reading accounts of veterinary service activities during the early twentieth century one is struck by a preoccupation with rinderpest control. In many countries this was the prime reason for the establishment of veterinary services just as rinderpest control had been one of the major motivations for establishing veterinary colleges in Lyons, France in 1761, and subsequently in other European countries and their colonies. It also was the impetus for the founding of both the Office International des Epizooties (OIE), now the World Organisation for Animal Health, in 1924, and the Food and Agriculture Organization of the United Nations (FAO) in 1945.

The main technical factors that made rinderpest a good candidate for eradication included the nature of the virus—rinderpest viruses all belong to a single serotype and one vaccine can protect against all existing viruses, there is no carrier state in the host, and there is lifelong immunity after exposure. The severity of the disease’s impact on trade and livelihoods was so great that it generated a strong political will to see the disease eliminated, and this fostered international collaboration and coordination. This spirit of international collaboration combined with the technical feasibility of eradicating rinderpest led to a call in the mid-twentieth century for the establishment of publicly funded rinderpest control programs, both national and international. The account given here describes the history of rinderpest and explores how eradication was achieved, providing some perspectives and analysis on the global impact of the disease and its eradication. The story of rinderpest eradication is a long one of death and destruction, failure and success. It is a story containing political intrigue, institutional failure, and reluctant institutional change, not all of which can be addressed here. It is also the story of scientific, political, and institutional innovation that, despite some failings, achieved dramatic success and changed world history.

In 2009, we can be assured that the rinderpest virus is no longer circulating in domesticated or wild animals anywhere in the world—it has been eradicated from its natural hosts. Notwithstanding the fact that the disease ranged freely and blighted the lives of farmers throughout Europe, Asia, and Africa for many centuries, today, in the first decade of the twentieth century few farmers and even fewer veterinarians have seen the disease and its memory is rapidly fading. The eradication of rinderpest can be viewed as a remarkable achievement on par with the eradication of small pox from the human population, the only other time that an infectious disease has been eradicated. This understanding is based not only on the absence of the disease, which was detected and confirmed for the last time in Kenya in late 2001, but also on the results of active surveillance programs established in key countries, which included serological studies designed to detect both overt and occult virus circulation. The majority of countries have achieved accreditation of rinderpest freedom by the OIE, even if the global accreditation task is still incomplete. While confidence in rinderpest freedom in the least developed countries translates into confidence in food production from cattle and buffaloes as well as dismantled trade barriers and increased trade in livestock and their by-products from previously infected countries, the full benefits of rinderpest freedom will not be realized until the accreditation process is complete. It merits stressing that the eradication of rinderpest alone will not free up the meat trade into the high-value markets of Europe and the Russian Federation, for example, because other diseases such as foot-and-mouth disease (FMD) will continue to inhibit it. Despite this constraint, cattle exports from Pakistan into the Middle East and Gulf States increased dramatically after a ban imposed because of rinderpest was lifted after Pakistan declared provisional freedom from rinderpest (FAO 2003). Ethiopia started similarly to export considerable quantities of cattle and beef to Egypt until FMD supervened to halt the trade.

A potted history of significant events marking progress towards global eradication is given in Table 1, illustrating a progressive decline in the geographic range and incidence of rinderpest in the twentieth century.

Table 1. A history of significant milestones in the global eradication of rinderpest

World Region	History
Europe, including European Russia	Elimination of rinderpest was achieved progressively from the eighteenth century and was completed in 1928, through the use of draconian legislation enforcing zoosanitary procedures, such as isolation and slaughter of infected animals, quarantines and movement certification, together with serum-simultaneous vaccination.
Southern Africa	The first great African rinderpest pandemic wreaked havoc when it reached southern Africa by crossing the Zambezi River in 1896 and led to international collaboration in the search for tools to control infection and in mounting control campaigns. Use of the serum-simultaneous vaccination procedure, combined with imposed zoosanitary measures, led rapidly to the invasion being repulsed from the whole of southern Africa by 1905. This procedure brought great benefits in terms of livestock production and trade and also undoubtedly contributed to the success of wildlife conservation in the region.
Russia east of the Ural mountains and the former USSR	Rinderpest was eliminated from the former USSR progressively from the 1920s through the use of zoosanitary procedures combined with immunization procedures including, latterly, cell culture grown vaccines. A small number of incursions from South Asia and China occurred in the early 1950s but border fencing combined with maintaining a vaccinated buffer zone the length of the former USSR border effectively excluded the virus, a process aided by the early elimination of rinderpest from China. Limited outbreaks in border areas of Georgia, Chitta and Tuva, and the Amur region in 1989 were related to vaccine use, not wild virus infection.
Southeast Asia and China	An intense war on rinderpest was waged in Southeast Asia by the countries themselves and aided by international assistance from the United Nations. The success achieved by 1957 was combined with progressive control of infection in the north of India to support control in China. The development of a vaccine there, which could be used effectively in all species, was a key event that, once peace prevailed, allowed concerted vaccination campaigns to eliminate rinderpest virus from the whole country by 1956. This result was evidently a great benefit to the people, whose staple diet was rice, as it allowed agricultural development and intensification of production to progress.
West and central Africa	Judging by the international campaigns, it was easier to control rinderpest in West and central Africa than in eastern Africa. The first internationally coordinated and funded campaign in Africa, Joint Project 15, rapidly cleared most of West and central Africa but left a reservoir of infection in the pastoral herds migrating between Mali and Mauritania. Because there was no follow-up vaccination, herd immunity waned and the virus emerged from this reservoir and entered into Nigeria, where rinderpest resurged from persisting infection reservoirs in eastern Africa. The devastation of this second great African rinderpest pandemic stimulated the fielding of numerous national rinderpest control projects between 1985 and 1988. These projects rapidly brought the disease under control, leaving only Ghana and Burkina Faso and the persisting focus in Mauritania and Mali to be addressed by the PARC, a new continental program started in 1986. This time the effort was successful, and rinderpest was not seen west of the Central African Republic after 1988. The successor to the PARC, the PACE program, operational from 1999 to 2006, helped countries to develop the epidemiological capacity to conduct the surveillance for rinderpest essential for accreditation. Most West and central African countries have achieved or are close to achieving freedom accreditation.
South Asia	Using its own resources, India waged a long war against rinderpest with increasing intensity throughout most of the twentieth century, using the whole panoply of immunizing agents as they were developed. Intensification of the NPRE in the 1980s brought progress in reducing the weight of infection in the northern states, which helped neighboring countries such as Nepal and Bangladesh, and thereby Myanmar, to control their own infections. Epidemiological clarification enabled control efforts to be focused to some extent and progress was made but the final goal to eliminate infection from the reservoir of endemic infection in peninsular India was not achieved until national efforts were aided by assistance through a project funded by the European Commission. India has remained free from rinderpest since 1995. After partition, Pakistan remained endemically infected with rinderpest and was a source of infection for Afghanistan and the Arabian Peninsula well into the 1990s. Intensive efforts from about 1999 concentrated on understanding the epidemiology of rinderpest persistence in Pakistan. Once it was ascertained that the Indus River buffalo tract of Sindh province constituted a persisting reservoir of infection, the formulation of a science-based, focused eradication program became possible. Farmer awareness grew and an ensured supply of quality assured vaccine enabled the elimination of infection to proceed rapidly; Pakistan has been reliably free from rinderpest since the last cases were detected in 2000. In turn, this improved situation reduced the risk of transmission to the Arabian Peninsula.

Table 1. (Continued)

World Region	History
Sudan and eastern Africa	Eastern Africa lagged behind in the eradication effort because, it is now clear, the persisting reservoirs of infection in the very large, remote and marginalized cattle herds of the pastoralists were not at first adequately addressed. JP15 came and went without greatly altering the problem of virus reservoirs and the PARC, despite some significant successes in Ethiopia, left behind a legacy of greatly reduced, but continuing, viral persistence in southern Sudan and the Somali pastoral ecosystem (comprising but not necessarily involving contiguous areas of Somalia, Kenya, and Ethiopia). The PACE contributed to capacity development while ancillary projects in Somalia, operated by nongovernmental organizations contributed significantly to rinderpest surveillance and control. In southern Sudan, the progressive control of rinderpest through community-based animal health programs implemented by various NGOs under the aegis of Operation Lifeline Sudan was a remarkable achievement. By 1999, rinderpest was occurring only in the cattle herds of two tribes and was eliminated by 2000 by intensive vaccination through Operation Lifeline Sudan, working closely with the PACE program's "The fight against African lineage 1 rinderpest virus" project and the GREP secretariat. The Somali ecosystem situation of supposed, but essentially spurious, virus persistence after 2001 was finally resolved by a project established under the PACE but continuing after its termination—the Somali Ecosystem Rinderpest Eradication Coordination Unit. Its intensive epidemiological studies in collaboration with the nongovernmental organization Terra Nova and the GREP secretariat demonstrated clearly by 2008 that rinderpest had ceased to circulate several years previously. Somalia is now well-placed to apply for OIE recognition of rinderpest freedom despite the political chaos that persists in the country. Rinderpest was last detected near Meru National Park in Kenya in October 2001.
The Middle East and Arabian Peninsula	Outbreaks of rinderpest occurred frequently in countries such as Yemen, Saudi Arabia, United Arab Emirates (UAE), Oman, and Qatar up to the mid-1990s. Epidemiological studies, based on molecular epidemiology, led to the conclusion that the major problem was repeated introduction of infection in traded cattle from South Asia, which gave rise to local epidemics persisting sometimes for years. Once the South Asian foci (essentially Pakistan at the end) yielded to control, the countries of the Arabian Peninsula could eliminate the disease. The last outbreaks were experienced in Oman in 1995 and Saudi Arabia, UAE, and Qatar in 1996. Rinderpest in Iraq seeded infection into Iran and Turkey until it was eliminated from all three countries in 1996.

Source: Authors' formulation.

Rinderpest eradication was neither the outcome of a single project or program nor due to the efforts of a single agency, but was rather the result of a series of periodic, concerted, and coordinated international efforts built on the ongoing national programs of many affected countries. If one views the start as the point when goat-adapted attenuated vaccines were readily available, then the process has taken some 70 years.

Describing the benefits of rinderpest eradication in financial terms is severely constrained not only by the paucity of studies conducted but also by the fact that international funding for rinderpest control was distributed to programs that covered many other issues, including privatization of veterinary services, generic surveillance, and control of other diseases such as contagious bovine pleuropneumonia (CBPP). The rinderpest control element is not clearly discernible and, thus, expenditure on rinderpest control can be easily overestimated.

Despite the overwhelming success in ridding the world of this devastating disease, two important gaps in research remain. First, there are too few analyses synthesizing the broad technical and coordination lessons that have arisen from the control of rinderpest. Given the existence and emergence of other virulent animal diseases (for example PPR, FMD, highly pathogenic avian influenza, porcine high fever disease, and African swine fever), it is critical that lessons derived from the rinderpest story be clearly explicated and shared. Second, even less information is available on the broad economic impacts of rinderpest control. As will be noted in this paper, while a few technical analyses of specific programs have been made, none of these has examined the broader pro-poor impacts that such control measures have had. This paper will attempt to illuminate some of these potential gains on the broader economy and on household welfare in selected cases, though further research will be required to adequately delve more deeply into specific livelihood effects.

2. THE HISTORY OF RINDERPEST: THE SETTING FOR GLOBAL ERADICATION

Early History and the Freeing of Europe

The written record of rinderpest occurrence in the world is relatively sparse in recent years, making it difficult to discern epidemiological patterns from recorded events; the overall picture of viral persistence is obscured by long-lived epidemic, even pandemic, waves of infection interspersed with periods of apparent disease absence. Generally, only exceptional events are reported and this was especially so in the modern era where reporting rinderpest occurrence came to be a sensitive issue because of its impact on international livestock trade. However, combining recorded history with an understanding of "grey literature" can provide insights into epidemiological patterns within the overall picture of viral persistence. Readers wishing for more detail on the epidemiology and the history of rinderpest occurrence and control should refer to the Rinderpest and PPR monograph edited by Thomas Barrett, Paul-Pierre Pastoret, and William Taylor (2006), and the detailed account published by Spinage (2003).

Waging war was a potent means of spreading rinderpest around and between Europe, Asia, and the Middle East. The large cattle herds travelling in the van of marauding armies were husbanded to feed the soldiers and provide draft power for their baggage trains or were amassed as the spoils of war for the victorious soldiers returning home. Repeatedly from as early as the fourth century until well into the twentieth century, rinderpest was spread by military campaigns. The Huns and Mongol invaders brought the disease from its homeland somewhere in the east of Asia into Europe. Asian Grey Steppe oxen were remarkably resistant to the effects of rinderpest and large herds could shed the rinderpest virus for months and provoke epidemics that devastated the cattle and buffalo herds of the invaded countries (Scott 2000). *Baghdadlis*—the name given to cattle traded to Egypt from Iraq during the early twentieth century, a huge trade—were similarly notorious for introducing rinderpest without themselves being seriously affected (Littlewood 1905).

War and civil disturbance continued to spread rinderpest until the late twentieth century: the Israeli and Syrian armies withdrawing from Lebanon in the early 1970s took rinderpest with looted cattle into their own countries; goats were incriminated in the inadvertent transfer by the Indian peacekeeping forces in 1978 of rinderpest to Sri Lanka, which had been free of the disease for 30 years; and, the civil disturbance caused by the Gulf War resulted in a major upsurge of infection in Turkey, Iran, and Iraq in the early 1990s.

The looting and social disruption of war was not alone in spreading rinderpest. Increasingly in the seventeenth, eighteenth, and nineteenth centuries, it was organized trade in cattle, largely from Russia, that repeatedly introduced rinderpest into recipient countries in Europe and elsewhere where, increasingly, it was spread by trade in livestock that was meant to feed the populations of the burgeoning cities. The "Russian disease" spread not only because of trade in cattle for meat per se but also as an indirect result of trade in corn transported in massive quantities by ox-drawn carts (Spinage 2003). The development of steam power in the nineteenth century enabled the shipment of live cattle by rail and sea in numbers previously impossible and, as a result of rinderpest, from 1857 to 1866 Europe was denuded of cattle.

Throughout the centuries, rinderpest pandemics raged across Europe from the Mediterranean and the Levant in the south and the Scandinavian countries in the north, and from Ireland in the west to Moscow in the east. For many centuries no European country was consistently free from rinderpest. A particularly severe European pandemic of cattle plague evolved over several years in the early eighteenth century and extended from Western Europe to Moscow and south to Italy, possibly originating there through cattle trade from Hungary to Dalmatia. To quote Spinage (2003), "There were many suggestions as to its origin in the countries affected, but for centuries, the herds of Venice and Lombardy had suffered invasions through commerce in cattle across the Adriatic." and "the outbreak of this plague in 1709 caused even greater terror in man than did the Black Death from which the populations of Europe were only just recovering...." This catastrophe was matched by another pandemic that lasted for a decade from

1745 and “swept away nearly the whole race of horned cattle throughout Europe.” These epidemics and pandemics set the pattern for Europe well into the nineteenth century.

The earliest attempts to provide a means of relieving the impact of rinderpest were constrained by a lack of understanding of aetiology and reliance on specious potions; unsurprisingly they did not prove effective (Mammerickx 1994). There was little rational thought about the issue until Bernadino Ramazzini, principal professor of medicine at Padua University in 1712, provided the first clear description of rinderpest, which allowed Giovanni Lancisi, the physician to Pope Clement XI, to formulate and publish technical recommendations for control based on an understanding of the contagious nature of the disease (Pastoret et al. 2006). The principles were progressively applied across Europe to bring about separation, confinement, and branding of infected animals to provide traceability, isolation of infected premises, and sanitary cordons around infected farms. Subsequently, selective embargoes on the import and export of livestock during epidemics were introduced together with health certification and the quarantining of traded cattle. Giovanni Lancisi and Thomas Bates, working in the United Kingdom, simultaneously recommended the culling of infected cattle as being the most effective method of control especially when made compulsory and combined with compensation, which was first paid in England in 1714, and finally the safe disposal of carcases (Blancou 2006). This process, which combined zoosanitary measures with strong legal enforcement, was markedly effective, setting the pattern for rinderpest control across Europe and leading to its eventual eradication in 1908.

Elsewhere the history of rinderpest occurrence and its impact is also quite clearly described.

Eastern Asia and Russia

The last global war of the 1930s and 1940s saw a major resurgence of rinderpest throughout eastern and southeastern Asia. As recently as 1957, in fact, Thailand appealed for international food aid because rinderpest had so reduced the numbers of buffaloes available to prepare rice paddies that rice production had been drastically reduced, causing famine to loom.

Long known as a devastating disease in China, during the war period from 1938 to1941, more than 1 million cattle died from rinderpest in western China (including Sichuan, Qinghai, Gansu, and Tibet provinces), and rinderpest occurred widely in China during 1948–49. With the understanding that agricultural development could not occur while rinderpest was causing such serious losses, the new government in 1948 made the elimination of the disease a priority. Success came rapidly and no outbreak has occurred since 1955; vaccination ceased permanently in 1956.

Rinderpest was first officially recorded in Mongolia in 1910 at which time annual losses approximated 120,000 cattle and yaks. Repeated reinvasions, controlled by movement restrictions and immunization, were noted in the 1930s and 1940s. Kurchenko (1995) referred to the conclusion from studies conducted in the 1950s that rinderpest had most frequently been introduced into the country by infected *dzeren* gazelles (*Procapra gutturosa*) during their migrations across the border with China, just as occurs today with FMD. From the 1950s, the country remained free until 1992 to 1993 when locally restricted outbreaks of rinderpest occurred on both sides of the Mongolian and Russian border.

By the strict implementation of severe legislation, which required the immediate slaughter of infected animals, rinderpest had been eliminated from European Russia by 1908, although it persisted in Transcaucasia (which includes Georgia, Azerbaijan, and Armenia) until 1928 (Laktionov 1967). However, the far east of Russia was repeatedly invaded by rinderpest from China and Mongolia until the 1930s and 1940s, with the last invasion occurring from the Manchurian region of China in 1945 and 1946. Further west, after the 1940s, the Central Asian republics were maintained essentially free from rinderpest apart from serious incursions into Turkmenistan in 1950 and Tajikistan in 1944 and 1951 from Afghanistan and Iran. This perception of long-term freedom from rinderpest made it difficult to understand how outbreaks could have occurred in Russia near the border with Mongolia in 1991 and in a single village in the far-eastern Amur region near the border with China in 1998. These enigmatic events, coupled with a similar event in Georgia in 1989, were eventually linked to the use of an attenuated vaccine that retained the ability to revert to virulence (Roeder et al. 2006).

Incidents of collective death, most likely due to rinderpest, were recorded twice in Japan during the seventeenth century, starting in the years 1638 and 1672, each lasting two to four years. However, the rinderpest virus was not constantly present in Japan; the history of rinderpest there is closely linked to that of China and Korea, also intimately connected, where rinderpest epidemics were repeatedly experienced, for example during the sixteenth and seventeenth centuries (Kishi 1976). Again, an upsurge of rinderpest in the Shanghai district of China in 1869 was mirrored by the appearance of the disease in Korea, where almost 50,000 cattle deaths were recorded in Korea's Yamaguchi prefecture (that nearest to Japan). By 1872 the disease had spread to Japan, leading to the deaths of more than 42,000 cattle. In all, from 1872 to 1911, there were 19 outbreaks of which 134 originated in Korea, four from China, and two from an unknown source. Death rates exceeded 90 percent, indicating the high sensitivity of Korean and Japanese cattle to rinderpest. Although the invasions of rinderpest in Japan continued to occur into the twentieth century, the last cases there were in 1924 and in Korea in 1931.

South Asia

In the Indian subcontinent, somewhat surprisingly, reports of rinderpest occurrence became frequent only in the late eighteenth century and, increasingly, into the nineteenth century. From that time, epidemics occurred regularly, repeatedly killing a significant proportion of cattle and buffaloes, the results of which influenced rinderpest ecology in the whole of South, Southeast and even East Asia.

Despite heroic attempts at mass vaccination for many decades in the twentieth century, and progress in limiting the disease impact and area affected, little progress was made in eliminating the infection until the 1990s.

The area that became modern-day Pakistan was severely affected by rinderpest throughout most of the twentieth century with major upsurges being suppressed by vaccination. The last such dramatic epidemic occurred in 1994 when rinderpest was introduced into the Northern Areas by buffaloes from the Punjab, where an upsurge of rinderpest, itself originating in Sindh province, had been recorded during 1993–94. Classical cattle plague resulted with more than 40,000 cattle, yaks, cattle and yak hybrids, and buffaloes dying during the first months of the epidemic (Rossiter et al. 1998). The epidemic spread slowly but progressively, until 1997 when it was eliminated by intensive vaccination campaigns conducted by the Government of Pakistan, with assistance from the FAO aided by the European Commission (EC). From 1999 the FAO mounted a program of assistance to Pakistan to eradicate rinderpest and from 2002 the European Union (EU) added additional valuable financial support for strengthening disease surveillance. Studies rapidly revealed that far from being ubiquitous as had been suspected, rinderpest had generally been restricted in the recent past to the southern part of the Indus River buffalo tract in Sindh province where reactive vaccination focusing on outbreaks suppressed the disease. Starting in the early 1990s, it appears that problems related to the quality of the rinderpest vaccine had led to both an upsurge of rinderpest along the Indus River in Sindh province and to the seeding of the virus into other areas. Epidemics such as those in the Northern Areas, other parts of Pakistan, in eastern Afghanistan and possibly as far afield as Iran, Iraq, and Turkey were the result.

The Landhi Dairy Colony near Karachi, founded in the 1950s to house 28,000 cattle and buffaloes, was one of several enclaves that became a home for hundreds of thousands of buffaloes and cattle. The colony became notorious for being continuously infected with rinderpest, yet studies between 1999 and 2003 clearly indicated that rinderpest had been eliminated from large dairy colonies such as Landhi. However, rinderpest continued to circulate in the small herds of buffaloes in the more remote areas of Sindh until October 2000 when the last cases of rinderpest were detected in small farms near Karachi (Hussain et al. 2001). In addition to routine and emergency disease-reporting systems, active village searches for evidence of rinderpest using a participatory disease-searching methodology (Mariner and Roeder 2003) were put in place throughout the country with a concentration on Sindh and Punjab provinces. The findings confirmed that rinderpest had ceased to circulate after 2000. Vaccination was withdrawn in 2000 and serological studies demonstrated freedom from infection, allowing the OIE to award Pakistan rinderpest-free accreditation in 2007.

History records only five outbreaks in Afghanistan since 1950, suggesting that rinderpest was a relatively rare event that resulted from periodic upsurges of the virus in Pakistan. However, rinderpest in Afghanistan was of major regional significance, since it moved on from there into Iran on several occasions, causing a pandemic in the Near East during the 1960s and 1970s (see below), and in 1950 and 1951 breached the defenses of the former Soviet Union to enter Turkmenistan and Tajikistan (as it had previously in 1944). In terms of rinderpest ecology, Afghanistan can be considered as an extension of the western Pakistan ecosystem because the two are linked ethnically, by contiguous livestock populations, by transhumance, and by two-way trade in livestock.

Bangladesh seems to have been free from rinderpest after 1958 in which year approximately 3 million cattle and buffaloes had died in the northeast of the country. Prior to that event, the history of rinderpest had been one of occasional introduction from neighboring countries with an epidemic spread within the country, but not of persistence. Rinderpest spread to Nepal from India on 13 occasions between 1952 and 1989, which was the last year the country was affected. After losing 25 percent of its cattle and yak herds in 1969, Bhutan remained free of rinderpest thereafter. Thus, as rinderpest was eliminated from northern India so did it depart from Bhutan, Nepal, and Bangladesh.

West Asia

Rinderpest repeatedly swept into Iran from its neighbors, causing great losses. The source could not always be identified, but until the 1990s they came primarily from the east—Afghanistan and Pakistan. A particularly severe pandemic in the Near East swept from Afghanistan through Iran to the Mediterranean littoral and into the Arabian Peninsula from 1969 to 1973, invading virtually all countries. Another wave of rinderpest engulfed Iraq from 1985, resulting from 600 Indian dairy buffaloes being introduced through the port of Basrah (or possibly via Kuwait). The buffaloes were distributed widely in Iraq and caused a countrywide virgin epidemic, which in Baghdad's Al-Fedeliya Dairy Village alone killed half the resident 30,000 buffaloes.

The last of the introductions into Iran from South Asia took place in the mid-1980s at which time there was a distinct change in the pattern of rinderpest movement. Incursions in 1987 and 1989 entered from the north of its western neighbor, Iraq, as also happened in Turkey. The rinderpest invasion of Turkey in 1991 caused alarm in Europe and was met by action for control from the FAO. An upsurge of rinderpest in the "Kurdish Triangle" (Iraq, Iran, and Turkey) in 1993–94 elicited a strong FAO response in the form of a regional project covering the three countries to resolve the rinderpest problem. Rinderpest persisted in the central and southern governorates of Iraq until September 1994 when the intensive, repeated vaccination of buffaloes and cattle organized as a national exercise eliminated it. However, it lingered on in the northern governorates until 1996 when it was last detected near Dohuk in feedlots, causing a very mild disease syndrome with a mortality rate of less than 5 percent. It was eliminated from there by intensive vaccination campaigns organized by the FAO between 1994 and 1996, using funds from the U.N. Oil for Food Program. These campaigns ended the pattern of outbreaks spreading from Iraq to Iran and Turkey.

Until the mid-1990s, the persistence of rinderpest in pockets in the Arabian Peninsula was supplemented by periodic reintroductions from India and Pakistan. For example, the disease appears to have been endemically established in Saudi Arabia during the 1970s and 1980s (Hafez et al. 1985), persisting until the mid-1990s in feedlots in Al Qassim and Al Hoffuf, which were stocked with both traditional indigenous and improved calves from dairy farms. The concerted vaccination of newborn colostrum-deprived calves eventually broke the transmission chain. The last reintroduction seems to have been into Qatar and Saudi Arabia, most likely through the United Arab Emirates, in 1996. The last of the rinderpest introductions into Oman occurred with Pakistani fighting bulls in the same year.

Rinderpest was reintroduced into Yemen in 1971 and generated an epidemic that persisted for many years with fluctuating incidence. The coastal Tihama region in particular experienced a high incidence of disease. From this region, milking cattle moved to highland markets and villages, leading to slowly evolving epidemics throughout the highland areas, with occasional years of exceptional incidence such as from 1987 to 1989 when there were more than 200 outbreaks recorded. The pattern continued into the 1990s. The last recorded outbreaks occurred at the turn of 1994–95 in widely separated villages in the extreme north and south of the country. Subsequent disease searching and serosurveillance under the aegis of a FAO project indicated that the virus had ceased to circulate after 1997.

The virus derived from the north of Yemen in 1994 was characterized as belonging to the Asian lineage, as were the other five viruses from the Arabian Peninsula—from Iraq, Yemen, Kuwait, Oman, and Saudi Arabia. The fact that all the viruses from the Arabian Peninsula are typed as Asian lineage suggests that the Horn of Africa had not been a source of rinderpest for the Middle East despite trade in cattle from Somalia. However, confidence is limited by the paucity of viruses available for study and anecdotal reports to the contrary. It is clear that the elimination of rinderpest from India in 1995 and the progressive reduction of the weight of infection in Pakistan from 1995 onward was an important factor in reducing the risk of rinderpest virus transmission by livestock trade to the Middle East, and that the elimination of the Iraqi reservoirs between 1994 and 1996 eliminated the risk of rinderpest resurgence within the "Kurdish Triangle."

North Africa

Despite several introductions of rinderpest during the nineteenth century, Egypt appears to have entered the twentieth century unaffected, but this did not last. In 1903, the virus originating in Asia Minor initiated an outbreak of mild disease (Littlewood 1905), which spread widely and persisted for more than seven years. From that time, Egypt was subject to alternating epidemics and periods of apparent freedom from the disease. Attempts to eradicate it in 1946 by introducing a goat-attenuated virus were unsuccessful. A severe epidemic was recorded between 1982 and 1986 when more than 11,000 cattle died. Once recognized for what it was, the infection was eliminated by a comprehensive vaccination campaign.

The rest of North Africa has never recorded the presence of rinderpest, except for Libya, which suffered a short outbreak in 1966; the circumstances are unclear but a virus was isolated as referred to by Singh and Ata (1967).

Sub-Saharan Africa

After its introduction into eastern Africa in the late nineteenth century, setting off the first great African rinderpest pandemic, rinderpest spread from the Indian to the Atlantic Ocean. The virus moved rapidly down the eastern seaboard of Africa in grazing animals both domestic and wild. It reached southern Africa in 1896 and it took until 1905 to drive the virus out using strongly enforced zoosanitary procedures combined with serum-simultaneous vaccination.

When the pandemic died down it left behind in Africa pockets of infection from which arose periodic epidemics and pandemics; this situation continued until the last years of the twentieth century. By 1918 rinderpest was rampant throughout all the colonies of West Africa, causing mortality of cattle, amounting to many hundreds of thousands annually and seriously reducing wild animal populations. In 1918 rinderpest spread southwards once again into what is now Zambia, causing great alarm at the prospect of re-establishing infection in South Africa, and this pattern was repeated many times from then on; in 1939 the virus spread was halted only 60 kilometers from the Tanganyika and Northern Rhodesia (now Tanzania and Zambia) border (Swan 1973). The epidemic was brought under control by a combination of quarantine measures, vaccination, and disease intelligence monitoring by veterinary officers from Nyasaland (Malawi), Northern Rhodesia (Zambia), and Tanganyika (Tanzania). After the end of 1940, rinderpest rarely moved south of the Central Railway Line of Tanzania (Branagan and Hammond 1965). Tanzania enjoyed years of disease freedom from about 1966 to 1982, when rinderpest was recognized in buffaloes in the Serengeti National Park, having spread clandestinely from Kenya in Maasai cattle. Subsequently, it was found that the virus was in fact extensively distributed across the north of the country, at first in wildlife and later in cattle. Emergency vaccination campaigns organized by the FAO in 1983 restored Tanzania's free status. Thereafter, the EC supported three nationwide mass vaccination campaigns from 1985 to 1987, aimed at ensuring the elimination of the virus by creating a highly immune cattle population; in all, 23 million doses of vaccine were administered. Freedom lasted until a similar incursion in 1997 linked to rinderpest reappearance in Kenya in 1994. Again, the virus was repulsed by an intensive emergency vaccination program with resources mobilized by the FAO and the African Union Interafrican Bureau for Animal Resources (AU IBAR).

At the turn of the nineteenth and twentieth centuries, Abyssinia (now Ethiopia and Eritrea) still harbored rinderpest; with public security returning to Sudan, local trade resumed across the border and rinderpest became a real threat to Sudanese livestock. Trade to Egypt from Sudan, established in 1904 and reaching 37,000 cattle transported by land and sea in 1918, was continually disrupted by outbreaks. Although eliminated periodically from certain areas the disease was still endemic in Sudan in 1961 (Jack 1961) and persisted until 2000 (Roeder et al. 2006).

Kenya, Ethiopia, Eritrea, and Sudan were continuously affected, periodically and repeatedly seeding rinderpest virus infection into Uganda, Tanzania, and what is now Rwanda and Burundi, with a notable epidemic occurring in 1920 and persisting in overt form until 1926 on Kenya's border with Uganda. Uganda's last persisting rinderpest reservoir in the cattle of the Karamajong people persisted until 1994.

Somalia suffered a severe outbreak in 1928 but rinderpest was brought under a degree of control by 1930, although it was constantly reintroduced from Abyssinia thereafter. From 1939 to 1953 there was no effective control and at the time it was considered to be widespread (Peck 1973). The record of rinderpest in Somalia is particularly meager but Macfarlane (1970) records that there were 25 outbreaks in the Benadir region (around Mogadishu) in 1969–70. The last cases of classical rinderpest are often stated to have occurred in 1974, when there was a large outbreak in the south. However, there is evidence (Mariner and Roeder 2003) for persistence in southern Somalia of a virus of reduced virulence, and periodic episodes of exalted virulence west of the Juba River, peaking in 1981, 1987, 1991–93 and 1996 (Mariner and Roeder 2003).

The Second Great African Rinderpest Pandemic

Residual reservoirs of infection in the Senegal River basin of Mauritania and Mali and in the Greater Horn of Africa were the source of a rinderpest resurgence that wreaked havoc throughout the sub-Sahelian zone in the early 1980s and converged on Nigeria. Nigeria's economic strength had created a high demand for beef, which was met by cattle traders supplying from as far away as the Sudan and Ethiopia in the east and Mauritania and Mali in the west, bringing rinderpest with them. Weak disease reporting systems led to a serious underreporting of rinderpest outbreaks and the emerging problem was not recognized until the pandemic was already well-established. The livelihoods of livestock herders were devastated and, facing the loss of their herds and destitution, many Fulani herders committed suicide. National emergency control programs, many aided by the FAO, brought the resurgence under control by 1986. These events were the stimulus to mount a continent-wide Pan-African Rinderpest Campaign (PARC) and ultimately for establishing the Global Rinderpest Eradication Programme (GREP).

3. VACCINES AND VACCINATION

Although, arguably, introduction of zoo sanitary measures marked the start of effective rinderpest control, the real onset of the virus' demise was signaled by the discovery in the 1880s in Russia (Semmer 1983) and in South Africa by a team lead by Arnold Theiler, that serum from a recovered animal had protective powers.

The subsequent development of rinderpest vaccines paved the way to establishing immune populations that could be safeguarded from infection and its effects. The fact that immunizing cattle with a live virus induced lifelong protection allowed individual herds to be protected indefinitely, if an initial vaccination campaign was followed by an annual follow-up vaccination of young replacement stock. Furthermore, it became clear that, applied on a wide enough scale, vaccination could eliminate rinderpest from a country and, conceivably, even provide effective international control. It was then only a question of time before rinderpest eradication became a compelling issue. The impetus to develop and improve methods of vaccinating livestock against rinderpest drove rinderpest control. However, the search for an effective vaccine was a long one.

Of critical importance was the seminal work demonstrating that, while convalescent serum provided short-term passive protection, the simultaneous administration of immune serum and virulent blood could produce an active immunity—the serum-simultaneous method of immunization had arrived. This method proved to be the most effective way of immunizing cattle against rinderpest, until the later development of attenuated virus vaccines, and it became widely used in both Africa and India. However, inoculated animals were potentially infectious and needed to be physically separated from non-inoculated animals. Stations to combat rinderpest were set up in several sites along the far eastern border of the Soviet Union. While it was imperfect, and led to the spread the infection, it was far more effective than anything that had gone before and by 1928, in the space of two to three years, the serum-simultaneous method had eliminated rinderpest from the whole of European Russia. The main drawback of the serum-simultaneous method, apart from its short shelf life, was that the virus inoculum, drawn from a reacting ox, often contained infectious piroplasms and induced disease in recipients.

A number of workers succeeded in the 1920s to immunize cattle with inactivated preparations of infected cattle tissues. Various inactivants, such as formalin, glycerine, and phenol, were used to make vaccines that were applied with some success in the Philippines, Thailand, Sri Lanka, and the Russian Far East until 1949. Inactivated vaccines were still in use in several African and Asian countries as late as 1963 (Vittoz 1963). Although safety was a distinct advantage, one series disadvantage was the short immunity induced. The waning immunity carried the risk of an unapparent infection occurring in vaccinated herds, with the virus spreading slowly but steadily until finally the majority of the group contracts a severe infection.

In India, virus passaged in adult goats eventually became attenuated for cattle but still produced pyrexia, mouth lesions, and diarrhea in Hill bulls, highlighting the importance of appreciating the existence of variable levels of innate resistance to rinderpest seen among different races and breeds of cattle. Already in 1928 there was a move toward the use of goat-adapted rinderpest virus within the serum-simultaneous method and from 1931 onward, it was increasingly used throughout South Asia as a vaccine in its own right. It was used in the successful eradication of rinderpest from Thailand after World War II (where it could only be used in cattle as it was lethal in buffaloes). In 1935 it was introduced into Burma (now Myanmar), and the goat vaccine was still being used to vaccinate cattle and buffaloes in Bangladesh and Myanmar as late as 1990.

A goat-attenuated vaccine developed from the virulent Kabete O strain of the virus and standardized in Kenya was eventually considered sufficiently attenuated to be used on Zebu cattle, but not European stock (Bos taurus breeds). In cattle, the goat-adapted virus was expected to provoke a temperature reaction in nearly all susceptible Zebu cattle; an absence of such reactions led to a suspicion about vaccine's quality. Between 1941 and 1948, the vaccine, referred to as KAG (Kenya/Kabete Attenuated Goat), was used in some 15 million head of cattle across East, West, central and North Africa.

A desiccated goat vaccine was introduced into Egypt in 1945 as a method of mass immunization to counter a reintroduction of rinderpest, and six months later the epidemic was eliminated. Goat-adapted vaccines were cheap and efficacious and the immunity induced was long-lived. However, they retained the problem of low temperature conservation, even when the keeping quality was improved by desiccation and storage under vacuum.

In Japan and Korea, rabbits were used to adapt the virus for serum-simultaneous vaccination attempts on ultra-susceptible breeds of cattle (Nakamura et al. 1943). After repeated passage it still caused occasional deaths, while in Indian and Mongolian cattle only minor reactions occurred. In 1941, the passaged virus was used safely and effectively in Mongolia unsupported by serum (Isogai 1944). Subsequently, the lapinized vaccine was widely used in Africa and Asia.

After extensive use in north China during the early 1940s, further work conducted from 1945 at the Chinese National Research Bureau of Animal Industry by the United Nations Relief and Rehabilitation Administration provided a vaccine (Nakamura III) that caused only mild reactions in cattle and buffaloes. Thereafter, with the return of peace, the FAO disseminated this vaccine to a number of countries including Egypt, Thailand, India, Kenya, Pakistan, and Ethiopia (Hambidge 1955).

From about 1950, Chinese workers at the Harbin Veterinary Research Institute set about developing a more satisfactory live attenuated vaccine because the Nakamura III vaccine was difficult to produce in the amounts needed. After many hundreds of passages in rabbits, goats, and sheep, a vaccine was eventually produced from lymph nodes and spleen, which was safe and efficacious in all species and breeds, even yaks and Korean cattle. In yaks, the duration of vaccine immunity was tested to exceed five years. This vaccine was used for the final eradication thrust in China (Roeder et al. 2006).

The advent of cell culture techniques led workers to adapt existing attenuated laboratory strains of rinderpest to this new substrate but it was not until Walter Plowright grew the virulent Kabete O virus in bovine kidney cells for 70 passages that there was a breakthrough; this tissue culture rinderpest vaccine (TCRV) produced neither lesions nor fever (Plowright 1962) and it was safe and immunogenic for cattle of all breeds, ages, and both sexes.

In Japan, the lapinized/avianized Nakamura III virus was grown on Vero cells to produce a strategic stockpile suitable for use in Japanese cattle (Sonoda 1983). Similarly, a strategic reserve of the Chinese lapinized/caprinized/ovinized vaccine is produced currently in a lamb kidney cell culture at the Harbin Institute in China.

A virulent rinderpest strain, isolated in Kabul in 1961 and maintained through 37 cattle passages, was subsequently attenuated by 70 passages in primary calf kidney cells at the Scientific Research Agricultural Institute in Kazakhstan and was introduced as a vaccine in 1978. The vaccine was used routinely in the border immune belt between the Soviet Union and neighboring countries, and to repulse introductions of rinderpest if needed. Known as K37/70, the vaccine, which was extensively tested during appraisal and subsequently widely used, was regarded as safe for use in cattle and yaks. Unfortunately, as described earlier, outbreaks of clinical rinderpest occurred in areas where this vaccine had been recently administered. Comparison of the F gene nucleotide sequence (bases 840 to 1161) by scientists at the All-Russian Research Institute for Animal Health in Vladimir showed that the K37/70 virus and the Kabul virus differ by only one base. Additionally, the vaccine and field viruses are virtually identical, suggesting a unique relationship between the two viruses (Roeder et al. 2006) and that the K37/70 can, and has, reverted to virulence and regained the ability to transmit among cattle on more than one occasion. As such, it appears that virulence can be regained very rapidly, not requiring the accumulation of a large number of point mutations. A virus with the genetic characteristics of Kabete O was apparently isolated from cattle with rinderpest clinical signs in Kenya and Tanzania in the 1990s. This could be taken to suggest that Plowright TCRV has a similar potential for reversion to virulence.

Arguably the only drawback of the TCRV was its heat liability. To achieve a distribution system independent of a cold chain, Mariner et al. (1990) developed a more thermostable variant of TCRV by modifying drying cycles and stabilizers. The vaccine made according to the new method, generally referred to as Thermovax, can be used in the field for up to four weeks at ambient temperatures in the tropics without cold-chain support, provided that it is sheltered from sunlight and excessive heat. This vaccine was widely used to great effect in Africa within community-based vaccination programs, particularly in remote areas of Sudan, Somalia, Kenya, Ethiopia, Tanzania, and Uganda as well as in Afghanistan.

Because no serological tests exist that can discriminate between vaccination and field infection, rinderpest is currently impossible to detect serologically in the face of ongoing vaccination and for several years after vaccination has ceased. Clearly a marked vaccine with a differentiating test would be of great benefit in the final accreditation stage of the rinderpest eradication program. Development of recombinant vaccines has been described by several groups of scientists (Yilma et al. 1988; Yamanouchi et al. 1993; Romero et al. 1994) using vaccinia or capripox vectors expressing the fusion (F) and hemagglutinin (H) proteins of rinderpest virus, either alone or in combination, and have been shown to be highly efficacious (Ohishi et al. 2000; Verardi et al. 2002). Combined with a differentiating serological test in the form of an enzyme-linked immunosorbent assay (ELISA) based on a baculovirus-expressed rinderpest N protein, a vaccinia recombinant vaccine expressing only F and H rinderpest proteins has been strongly promoted (Yilma et al. 2003). Unfortunately, the N-based ELISA has shown performance characteristics that render it unacceptable as an OIE-prescribed test (OIE 2004) and to date none of the recombinant vaccines have been licensed for general use. An alternative approach has been to explore the production of positively marked vaccines by inserting genes for the expression of jellyfish green fluorescent protein and influenza A hemagglutinin into the Kabete vaccine strain of rinderpest virus (Walsh et al. 2000). The hemagglutinin-marked vaccine retained immunogenicity—and with its companion indirect ELISA to detect the strong hemagglutinin antibody response—appeared to have potential for field use, as did a PPR recombinant vaccine (Diallo et al. 2007). However, none of these recombinant vaccines have been used in vaccination programs and it is unlikely that this will happen now that rinderpest vaccines are no longer routinely used anywhere in the world.

4. CAMPAIGNS DESIGNED TO CONTROL OR ERADICATE RINDERPEST FROM ASIA

The first major campaigns aimed at eliminating rinderpest began in Asia as the world recovered from World War II. In addition to a coordinated effort that saw rinderpest eliminated by a FAO-supported regional program in support of national efforts across Southeast Asia, two major national campaigns stand out: one in China, which was rapidly successful, and the other in the Indian subcontinent, which took almost 50 years to achieve its target.

China

During the war period of 1938 to1941 more than 1 million cattle died from rinderpest in western China, and rinderpest spread widely in 1948–49. In 1948 cattle plague was killing millions of cattle, buffaloes, and yaks and the new government decreed that its eradication was to be a priority for it was realized that agricultural development could not occur unless the disease was removed from the equation.

An intensive vaccination program was at first constrained in China because early live vaccines retained unacceptable virulence for some breeds of Chinese cattle and yaks. However, passage of the Japanese lapinized vaccine virus in goats and sheep produced a safe attenuated vaccine. Clearing pockets of infection in the Himalayas at a time when there was little or no motorized transport and no refrigeration involved heroic feats. Chinese animal health staff transported the vaccine virus in live, infected sheep on the back of yaks and horses to the sites where the vaccine was produced for immediate use (Figure 1). This campaign had achieved success by 1955, but it was not until 2008 that China was accredited by the OIE as free from rinderpest.

Figure 1. Qinghai Animal Husbandry Division staff in 1954 transporting goats on horseback after their inoculation with caprinized vaccine virus.

Source: Courtesy of Yang Shibiao.

India and Pakistan

Edwards (1927-28) drew a distinction between countries in which movement control was acceptable, and countries (such as India and many African countries) where it was impractical or even impossible to impose. He also foresaw that the eradication of rinderpest from India could be achieved if it all the cattle could be rendered completely resistant *for a short time*—provided, of course, that there was no reinvasion from outside.

The Indian goat-adapted vaccine was used alone without immune serum from 1931 onward but, despite the distribution of significant amounts (although small in relation to the size of the cattle population) of vaccine over five years, progress toward eliminating infection was disappointing. By 1939 the availability of the vaccine had failed to make a profound or permanent impression on the total mortality rate due to rinderpest.

A vaccination plan developed in 1953 envisaged the mass vaccination of 320 million head of cattle, buffaloes, sheep, and goats during a 5–10 year period. By 1954, India had gained sufficient confidence in the attenuated goat vaccine and in the strength of their veterinary services to embark on this publicly financed, vaccine-based campaign—the National Project on Rinderpest Eradication (NPRE). The program aimed at systematically vaccinating 80 percent of the population of cattle and buffaloes in a period of five years, succeeded by a follow-up period of indefinite length (until the disease was eradicated) in which the remaining 20 percent plus the annual calf crop would be vaccinated (Taylor et al. 2006).

Each state undertook its own vaccination program and the results were variable. For example, in Uttar Pradesh, the main campaign lasted for eight years (1956–64) and resulted in a dramatic decrease in the incidence of outbreaks. Follow-up measures continued for at least another 20 years but did not prevent reintroduction. Similarly, in Andhra Pradesh, mass vaccination from 1956 to 1961 reduced rinderpest occurrence to zero but, even though escalating quantities of vaccine were administered during the next 23 years, the incidence rate remained intractably high. Without seromonitoring it is difficult to be certain of the reason but, obviously, sufficient susceptible animals remained to sustain the transmission of infection. Overall, mass vaccination succeeded in eliminating endemic rinderpest in some states but not in sustainably preventing its reintroduction; nationally, the program was unable to eliminate infection from the national herd although it did bring considerable benefits to farmers.

By the mid-1980s it was clear that the NPRE was failing. There did not appear to be a management solution to the overall problem of recurrent endemicity and to a large extent the whole program had become institutionalized. In 1983, a Government of India task force, convened to revitalize the eradication program, foresaw the need for a time-bound program of three years duration. In addition, it made an epidemiological analysis of the rinderpest situation in the various states, which suggested that the virus was endemic in the states of peninsular India, non-endemic but occasionally introduced into the states of north-central India, and absent from the northeast states of India. In the endemic states, it was advised that mass vaccination be reintroduced, aiming at 90 percent coverage within three years. Elsewhere, focused vaccination would be undertaken in the event of an outbreak. In this event, it required the coordinating efforts of a donor (EC) to bring about progress. Eventually, a focused vaccination was implemented in southern India and institutionalized mass vaccination was ended in northern India. The NPRE promoted strict movement control and probably assisted in reducing the number of infected animals being distributed from southern India to northern India. Rinderpest was eradicated from its last reservoirs in southern India in 1995 through the impact of vaccination on the sustained virus transmission chain.

Lessons drawn from the Indian experience included:

- eradication programs require clear initial objectives, constant management, and clear exit strategies and should be designed on a basis of epidemiological understanding;
- vaccination can be a very effective tool for disrupting the spread of rinderpest—the more intensively it is applied, the more rapidly it achieves the desired objective;

- as the number of outbreaks decreases, opportunities for enormous savings in time, labor and vaccine in switching from mass vaccination to focused vaccination;
- management of the Indian vaccination program was severely hampered by a lack of seromonitoring as a quality assurance procedure for vaccines and vaccination;
- one of the hardest issues to address is to persuade authorities to abandon institutionalized vaccination in areas free from foci of persisting infection, and to change to a reliance on focused vaccination should there be reintroduction; and
- effective management of rinderpest eradication programs involves taking carefully calculated risks—the reality of a time-bound program illustrates the need for such adaptive management.

As described earlier in this paper, success in Pakistan was delayed until its national program was supported by technical and financial assistance from the FAO and the EC to mount epidemiologically directed control.

5. AFRICA: RINDERPEST CONTROL, MASS VACCINATION AND ERADICATION

National authorities struggled individually to control rinderpest with varying success from the 1940s onward, but international collaboration in a coordinated approach did not commence until the 1960s. Three campaigns have occurred since that time, ostensibly designed to control or eliminate rinderpest from the African continent, organized with donor assistance under the aegis of the Organisation of African Unity/African Union's Joint Project 15 (JP15), the PARC, and the Pan-African Programme for the Control of Epizootics (PACE) .

Joint Project 15

The eradication of rinderpest from Tanzania between 1940 and 1966 was attributable to the well-managed use of live attenuated rinderpest vaccines in campaigns designed to progressively restrict the area (in essence the Maasai ecosystem), within which the virus was persisting. The final campaigns were focused in northern Tanzania at the site of the last small observed outbreaks. The ability to reach such a favorable conclusion reflected, in large part, the fact that on all but the northern border, Tanzania was free from the threat of re-infection, and Kenya to the north was actively eliminating the threat of rinderpest.

The first resolution of the African Rinderpest Conference of 1948 had stated that "it is the considered opinion of the Conference that in spite of any agricultural, sociological or administrative repercussions, control of rinderpest with a view to its complete eradication is desirable and necessary in the interests of Africa as a whole." This conference further resolved that "rinderpest can be eradicated from Africa with the biological immunizing agents already at our disposal." The conference also recognized the need for international collaboration in such an undertaking and recommended the establishment of an African Information Bureau on Rinderpest (which evolved first into the Interafrican Bureau of Epizootic Diseases and later into the AU IBAR). Latterly there was a growing awareness that the tool for an attempt at eradication had become available in the form of a freeze-dried live attenuated vaccine—TCRV.

Thus, in 1961 the Commission for Technical Cooperation in Africa South of the Sahara (CCTA), at a meeting held in Kano, Nigeria, decided on a program of joint action against rinderpest, with the intention of creating a rinderpest-free zone comprising the 8 million cattle around the Lake Chad basin, involving contiguous areas of Cameroon, Niger, Nigeria, and Chad. This JP15 operation aimed to use TCRV to eliminate rinderpest from the zone. For the first time since the development of large volumes of live attenuated vaccines in Africa, they were to be used in a highly intensive manner, vaccinating the entire cattle herd of the zone during each of the three years of the campaign. The campaigns marked the start of international cooperation and coordination in rinderpest eradication in Africa. Significant progress was achieved during the campaign between 1962 and 1965, as is illustrated in Table 2.

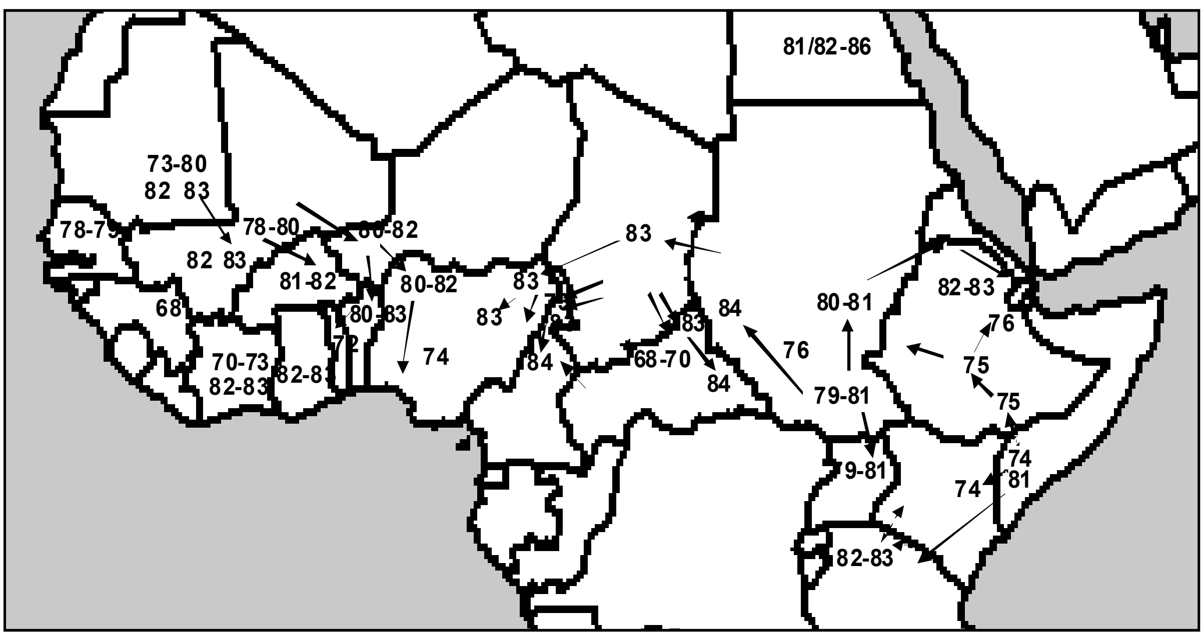
Table 2. Rinderpest vaccination coverage achieved during the first three years of the JP15 vaccination campaigns compared to the annual incidence of outbreaks

	Cameroon	Niger	Nigeria	Chad
Average number of outbreaks per year in previous 10 years	148	196	375	250
1962 –63				
Percentage of herd vaccinated	85.9	80.0	71.8	85.8
Number of recorded outbreaks	0	47	91	37
1963 –64				
Percentage of herd vaccinated	95.0	98.9	87.8	93.4
Number of recorded outbreaks	2	18	2	6
1964 –65				
Percentage of herd vaccinated	87.0	93.7	92.5	92.3
Number of recorded outbreaks	0	4	2	4

Source: Taylor 1997.

During 1962–1969, approximately 100 million doses of TCRV were used in JP15, and in West Africa rinderpest seemed to have been consigned to history but, as is now very clear and was well-known locally, a focus of infection remained in the pastoral community spanning the Mauritania border with Mali, from which re-infection of a number of countries occurred in the late 1970s. Although difficult to find in published reports and papers, there is clear evidence of the post-JP15 emergence of rinderpest from the remaining foci of infection, and the continued cycling of rinderpest virus in Sub-Saharan Africa after JP15 ended (Figure 2).

Figure 2. Rinderpest occurrence in cattle and wildlife in Africa between 1968 and 1984



Note: Numbers represent the last two digits of the year of occurrence of a rinderpest event, placed to indicate the approximate site of the event. Where known, linkages between outbreaks and direction of movement of infection are indicated by arrows.
Source: Largely based on Woodford et al. 1984; the Ethiopian events are from personal (PLR) experience and information.

Based on the perceived results of the first phase, JP15 was progressively extended across West and central Africa where it enjoyed remarkable success. Later its activities extended to eastern Africa, where it lingered on until 1977 in Ethiopia, but with limited success in terms of area-wide eradication. When the phase of intensive, internationally coordinated vaccination ended, maintaining a serviceable herd immunity was devolved to national veterinary authorities. This effort was largely ineffectual and wasteful. In Nigeria, for example, there is no doubt that the last case of rinderpest occurred in 1976, yet, as in many countries, annual vaccination campaigns continued for many subsequent years.

What was to blame for the resurgence of rinderpest as JP15 faded away? JP15 never developed an exit strategy other than to have national veterinary services eliminate the last vestiges of infection, which most of them did. However the failure to resolve the three or four persistent reservoirs of rinderpest infection in West and eastern Africa, and even to officially recognize that these were present, led to the undoing of most of the benefits. In fact, the campaign was not mandated to monitor the posdt-JP15 situation in countries. The only body in a position to understand that the virus had not been totally eliminated was the OIE, on the basis of voluntary reports that they received, and this proved to be ineffective at that time. Ultimately, international leadership failed to recognize the seriousness of the problem. Consequently, an OIE Pathway was developed in 1989 to provide exit strategies in the shape of accredited freedom from rinderpest. It is often quoted that the main failing of JP15 was the lack of a seromonitoring tool but, more plausibly, it was the lack of surveillance systems and epidemiological knowledge concerning virus persistence combined with an excessive reliance on institutionalized mass vaccination that contributed most to its failure.

The Pan-African Rinderpest Campaign and its Successor, The Pan-African Control of Epizootics (PACE) Project

The Pan-African Rinderpest Campaign (PARC) was initiated in 1986 to take on the task of rinderpest eradication in up to 34 countries of Africa and ran until 1998. Funded primarily by the EC, through a coordination unit within the AU IBAR in Nairobi, the PARC laid down strategy guidelines to be followed by individual national veterinary services. In fact, a PARC Epidemiology Unit to which the FAO made a significant contribution was based in the AU IBAR to undertake epidemiological studies and help set strategy. Although mass vaccination against rinderpest was the principle weapon to be used, an interesting aspect of the PARC's use of vaccine lay in the concept of immune belts and how these could be manipulated, together with the first attempts to grapple with the problems of verifying virus elimination.

It must be remembered that the PARC was borne out of the reappearance of rinderpest over large tracts of Sub-Saharan Africa during the second great African rinderpest pandemic of the early 1980s, which could not be contained by the veterinary authorities because financial and physical resources were lacking. Phase 1 of the PARC was designed to reinstate the capacity to administer the vaccine and, without naming measurable goals, a good measure of control over the disease was expected from the creation of immune populations. Thereafter, in what was called phase 2, residual endemic foci would be dealt with by coordinated eradication strategies. The endemic foci would be ringed by sanitary cordons made up of highly vaccinated populations and within the cordons, virus "elimination campaigns" would be mounted, again consisting of intensive vaccination to generate herd immunity levels within which the circulation of the virus could not continue. Thereafter, "run down" activities would be implemented, which would consist of lifting the vaccination and providing intensive disease surveillance.

Based on more reliable estimates of the virus' distribution—with East Africa being more heavily contaminated than West Africa—in 1988 the PARC developed the concept of the West African Wall. The wall was to split coastal from Sahalian states, thereby allowing progress toward eradication to proceed at different rates, and the creation of a blockade in the central African states of Chad and Cameroon to prevent the recontamination of West Africa from East Africa (Taylor et al. 2006). A containment cordon around southern Sudan was also suggested and elements of this were established in the Central African Republic and Chad, even if only in theory. In practice the central African sanitary cordons were not managed well enough for them to operate as a real barrier to the movement of rinderpest. In retrospect, the fact that the rinderpest virus did not cross the zone from southern Sudan in the 1990s owed more to the progressive reduction of the weight of the rinderpest infection in Sudan than to the efficiency of the sanitary cordon. The sanitary cordons were apparently not tested, yet the perception that they afforded protection to West African countries, real or not, was instrumental in giving them the confidence to withdraw routine vaccination as realization grew that rinderpest was limited to the Greater Horn of Africa.

In Ethiopia, at the start of the PARC, a pattern of rinderpest persistence in discrete reservoirs and the extension of epizootics from them was established, and this understanding was used as a basis for developing a novel eradication strategy.

Attempting to provide nationwide vaccination coverage would have required the annual vaccination of at least 30 million cattle. This effort had been attempted for many years but not even one third of this figure had been achieved. A strong team of veterinarians working with the PARC and the Fourth Livestock Development Project pioneered a strategy that set aside countrywide mass vaccination as unnecessary and unachievable. The new approach sought to contain the rinderpest virus within the reservoirs and focus vaccination efforts on eliminating infection from them, while establishing minimal vaccination buffer zones to protect especially vulnerable areas, and strengthening surveillance and emergency preparedness should infection escape. Key to this plan was the fielding of community-based animal health workers for work in insecure areas of difficult access and the use of a thermostable rinderpest vaccine to achieve high herd immunity rates. The new strategy required the vaccination of less than 3 million cattle per year. After a major struggle for acceptance, the strategy was implemented starting in 1993 and rapidly proved successful, despite challenges. The last incidents of rinderpest were reported in 1995 in the Afar region reservoir and on the Sudanese border in the southwest, having crossed the border in migrating cattle. This success was a major breakthrough that had a major impact on the design of future eradication programs in both Africa and Asia.

At the end of the PARC in 1998, it was reliably known that the rinderpest virus was still circulating only in southern Sudan and northwest Kenya as well as in southern Somalia and northeast Kenya, a remarkable achievement.

Again funded by the EC and coordinated by the AU IBAR, the PACE project ran from 1999 to 2006 in 32 countries. While still retaining a focus on rinderpest eradication, the project diversified considerably in different African regions to address other diseases, primarily contagious bovine pleuropneumonia control, and to strengthen "epidemio-surveillance" systems in a generic manner. The basic premise was that if veterinary surveillance systems could be strengthened, rinderpest control leading to eradication would improve as a result. Despite considerable success in some countries, capacity development was disappointing overall. The reasons are not clear.

A PACE team based in Nairobi provided epidemiological and strategy expertise to address the ongoing problem of rinderpest in the Somali pastoral ecosystem and the accreditation of rinderpest freedom in all other member countries. They were very effective in doing so. When the team was dispersed, it had provided the basis for countries to finalize rinderpest freedom accreditation and by establishing a Somali Ecosystem Rinderpest Eradication Coordination Unit (SERECU) had set the mechanism to work with the GREP secretariat to resolve arguments about whether rinderpest continued to circulate after its last confirmation in 2001. SERECU made a seminal contribution to enabling the three countries to apply for the OIE accreditation of rinderpest freedom. The PACE SERECU work will continue to be supported into 2010.

It is now clear that when the PACE program was terminated in 2006, rinderpest was no longer circulating in either its wild or domesticated hosts, thus bringing to a successful close the African, and indeed the global, rinderpest chapter.

The development of the community-based animal health worker programs added significantly to both the delivery of rinderpest vaccines and the understanding of rinderpest epidemiology in remote pastoral communities (Leyland 1996). Developed by nongovernmental organizations (NGOs) under the aegis of the United Nations Children's Fund (UNICEF) operating within Operation Lifeline Sudan, rinderpest control was a lynchpin of the community-based programs and these NGOs proved to be extremely effective in reducing progressively the weight of infection and its geographical range in southern Sudan. Intelligence gathering, based on participatory rural appraisal techniques and generically described as participatory epidemiology (Catley 1999; Mariner and Roeder 2003), is a nascent science in its own right, which with the participatory animal health service delivery systems, made a very significant contribution to rinderpest eradication (Mariner et al. 2002). Born in eastern Africa, participatory epidemiology has spread to Pakistan, Tajikistan, Uzbekistan, and Afghanistan where it has strongly enhanced disease surveillance for rinderpest freedom accreditation and disease impact assessments for programs managed by the FAO. It has found application not just for rinderpest in searching for infection reservoirs and determining rinderpest freedom, but also for a panoply of animal diseases, including such major problems as classical swine fever in Bolivia and highly pathogenic avian influenza in Indonesia (Jost et al. 2007). At first denigrated but later embraced by the AU IBAR, and specifically developed and used by its Community Animal Health and Participatory Epidemiology Unit (now migrated to become the Institutional and Policy Support Team [IPST][1]), the participatory techniques are an important legacy of the PARC and PACE programs.

Experience gained from the PARC and PACE indicates that management needs to be adaptive and flexible with a clearly focused perspective of what is to be achieved. The programs need to be formulated and run with the benefit of sound technical knowledge. The staff providing technical assistance to the regional coordination units and national units need to be of the highest caliber with international credibility, and able to network within countries and internationally. Sound epidemiological understanding is one of the major factors required for success.

Diagnostics, Seromonitoring, and Focused Vaccination

From the 1980s, in association with the PARC, the Joint FAO/International Atomic Energy Agency (IAEA) Division of Nuclear Techniques in Food and Agriculture, Animal Production and Health section provided technical guidance and assistance to the AU IBAR for the PARC by coordinating seromonitoring campaigns for rinderpest and evolving their focus to support diagnosis and serosurveillance. This, and a matching network established in West Asia, provided a technical support base, invaluable fora for information exchange, and the coordination of technology transfer to participating countries. The work in Africa continued as a PACE activity into 2004, funded by the EC through the FAO.

Regular assessment of the efficacy of vaccination programs was widely perceived to be an important component to ensuring the success of the PARC, and was promoted vigorously by the FAO/IAEA Joint Division. In 1986, a coordinated research program was established—known as the sero-monitoring of Rinderpest throughout Africa—and subsequently maintained in the PACE program until 2004. Central to the program was the availability of enzyme-linked immunosorbent assay (ELISA) technology for testing the large numbers of serum samples obtained; fundamental to the concept was an understanding that if the overall herd immunity level could be raised to more than 80 percent[2] then the rinderpest virus would stop circulating in that population. Implicit was a related concept that if seromonitoring disclosed inadequately vaccinated populations then action would result in revaccinating those populations. Intellectually attractive as it was, in reality it proved to be very difficult to obtain the serological data in time to influence the conduct of vaccination programs. Even in Ethiopia, where vaccination was conducted within a dynamically managed national PARC project, linking seromonitoring data to vaccination programs provided little more than a retrospective analysis of vaccination efficacy. The principle was applied much more successfully outside Africa, by the national authorities in Iran where seromonitoring was rigidly applied to assessing and enhancing the efficacy of annual pulsed vaccination programs, and was also effectively applied by the FAO in emergencies in Afghanistan and in Tanzania (Taylor et al. 2002).

[1] Further information is available on-line at <http:/cape-ibar.org>. Accessed on August 9, 2009.

[2] The level of herd immunity required to disrupt rinderpest virus transmission is variously quoted as being between 80 and 90 percent but these figures are empirical and not adduced from epidemiological studies (Roeder et al. 2007).

The potential value of seromonitoring is demonstrated by action taken after a mild form of rinderpest was detected in northern Tanzania, apparently having spread from southern Kenya in January 1997. This spread constituted an international emergency for which Tanzania requested international assistance. The response plan was to define the area into which the virus had penetrated and to provide focused vaccination aimed at raising the level of herd immunity to an extent that viral transmission would be disrupted. In this particular emergency, the low virulence of the strain made it difficult to determine the area of infection, and so a combination of serological and clinical evidence had to be used. Eventually, emergency vaccination was initiated by two campaigns conducted in tandem. The results of two seromonitoring programs, each conducted within three to four weeks of the end of the field vaccination campaigns, revealed that the first campaign had failed to achieve a level of immunity considered desirable to halt transmission (85 percent) and accordingly a second round of emergency vaccination was immediately organized. The results of the second round of seromonitoring proved satisfactory, with a high prevalence of village cattle populations obtaining an antibody prevalence of more than 85 percent. These populations were considered to have been "immunosterilized" (Taylor et al. 2002).

The U.K. Institute for Animal Health, Pirbright Laboratory, was designated by the FAO in 1994 as the World Reference Laboratory for Rinderpest (WRLR). Its provision of diagnostic and molecular technology for morbilliviruses made an invaluable contribution to the epidemiological understanding that informed control strategy. Molecular epidemiology demonstrated the existence of three extant clades (lineages) of the rinderpest virus that had been responsible for outbreaks of rinderpest in the previous 50 years: the Asian lineage and African lineages 1 and 2, limited to the African continent. Characterizing viruses from outbreaks proved valuable in determining their origins. The FAO/IAEA Joint division drew heavily on WRLR expertise to establish and run its African and West Asian laboratory networks.

The Value of Vaccine Quality Assurance

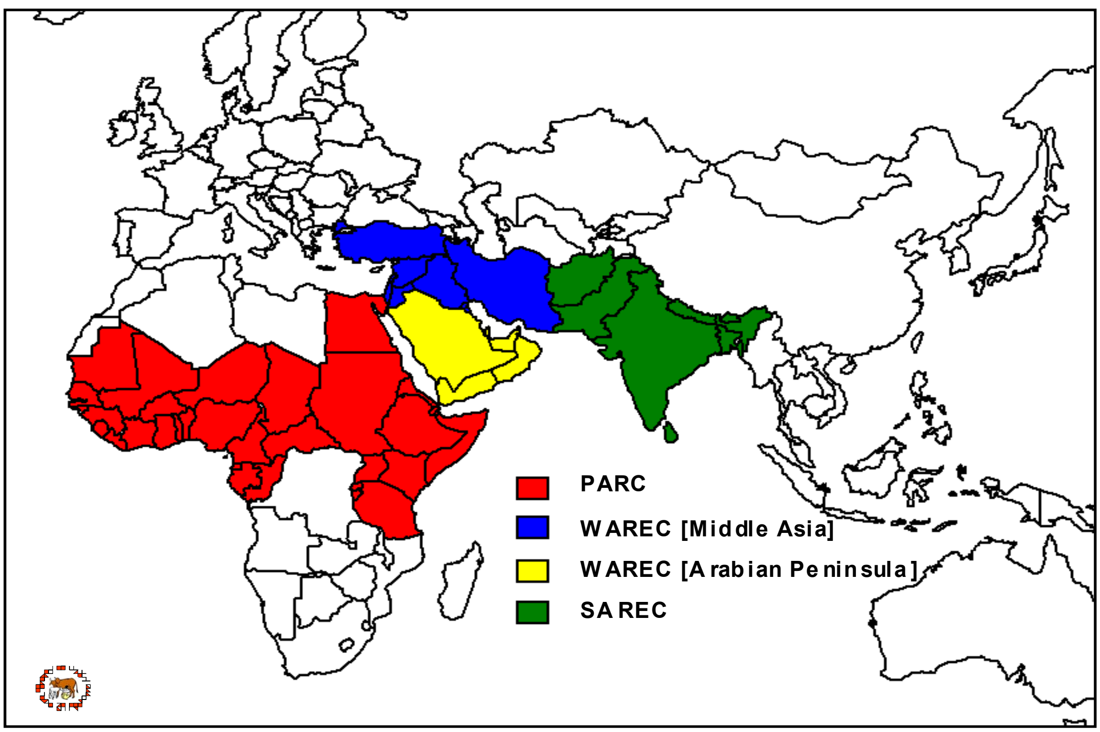
Early in the course of the PARC, it was realized that one of the factors limiting the efficacy of vaccination programs was the variable quality of the rinderpest vaccines being produced by a number of laboratories. To resolve this issue, the FAO established the Pan-African Veterinary Vaccine Centre (PANVAC) operating from two sites in West and East Africa. With some breaks in service, closure of the West African site, and fluctuations in resource availability, PANVAC, hosted by the Ethiopian Government, has continued to function as an independent autonomous unit until today. It is now institutionalized within the AU IBAR. Originally, the intention was to provide a rinderpest vaccine quality assurance (QA) service to the OAU IBAR in the implementation of the PARC. As part of technical development, standard operating procedures for vaccine production and QA were defined, published by the FAO, and incorporated into OIE guidelines. PANVAC was highly successful. The quality of vaccines increased rapidly from an initially low pass rate of less than 60 percent in 1994 to more than 90 percent by 1997, and the main reason for failure was mycoplasma contamination, not lack of potency. Even more importantly, the availability of the assurance system enabled PARC managers to insist that only PANVAC-certified vaccines were to be used in national rinderpest eradication programs. Possession of a PANVAC QA certificate soon became a prerequisite for buying rinderpest vaccines for use in Africa as well as in any country where the battle against rinderpest was being waged. The QA procedures developed were applied broadly and, for example, transfer of vaccine production and QA technology to Pakistan by PANVAC staff in 1995 can be seen now to have been a decisive factor in eliminating rinderpest from that country.

6. INTERNATIONAL COORDINATION OF RINDERPEST ERADICATION

Conceived in 1992 and operationally prepared in 1993, the GREP has operated under the auspices of the FAO Animal Health Service's Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases (EMPRES) to provide a coordination mechanism and source of technical guidance since 1994. Although the FAO initiated the GREP and hosts the GREP secretariat, the program should be viewed as the sum total of all activities that contributed to the final eradication of rinderpest in 1993.

The GREP was designed from the outset as a program rather than as a campaign, and one of its most valuable attributes has been that it is a time-bound program with a deadline of 2010 for accredited global freedom. An initial concept of the GREP was that rinderpest-control activities would proceed with international coordination on three fronts: PARC in Africa, the West Asian Rinderpest Eradication Campaign (WAREC), and the South Asian Rinderpest Eradication Campaign (SAREC) (Figure 3). The international community would fund these campaigns, often with nominal national contributions, and regional organizations would implement them. The first of these, the PARC, was implemented by the OAU IBAR with EC funding from 1986 to 1998. WAREC, with United Nations Development Programme funding, brought coordination to the Middle East until the Gulf War caused its collapse by 1994. SAREC was never implemented although the EC did fund a number of national projects in India, Bangladesh, Nepal, and Pakistan that contributed significantly to the South Asian rinderpest eradication process.

Figure 3. The campaigns that were expected to implement GREP

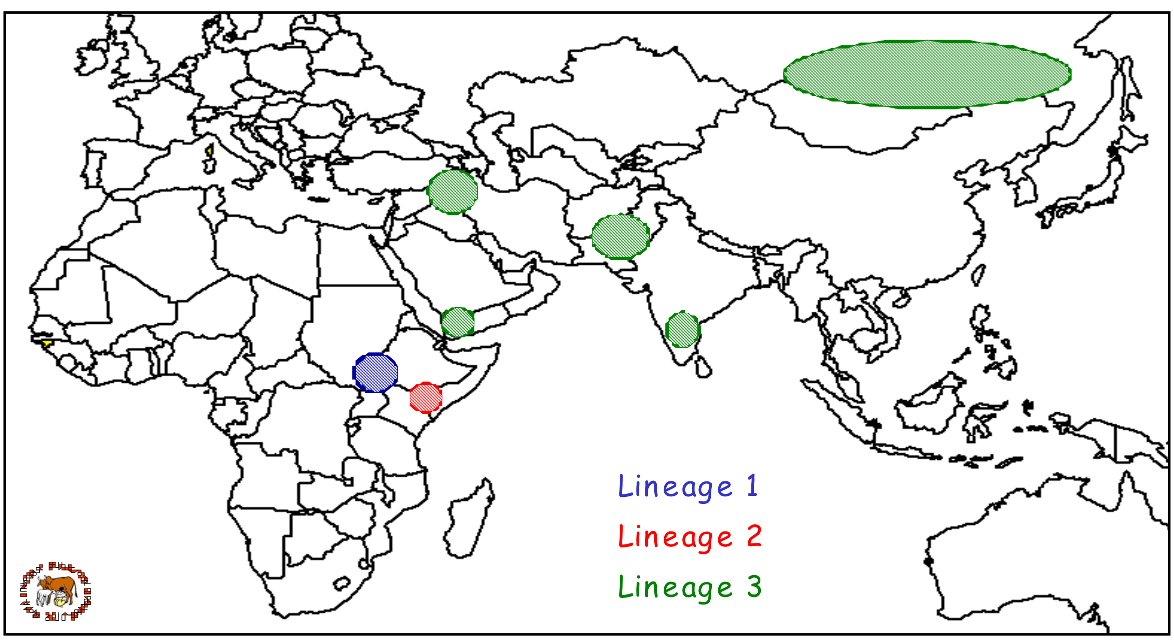


Source: FAO GREP.

The GREP's role in Africa was largely to advise the AU IBAR on technical issues and to fill lacunae within the PARC/PACE by providing complementary programs for areas of special need such as the Sudan. In Africa, relationships between the international organizations involved in the PARC and PACE—the EC, the AU, and the FAO—were not always smooth as differences emerged at times over the projects' diversification into broader development issues, the technical approach taken to eliminating rinderpest from countries, and program resource management. Although disputes might have delayed the eradication effort somewhat and constrained the sourcing of funding, fortunately these did not prevent the timely eradication of rinderpest.

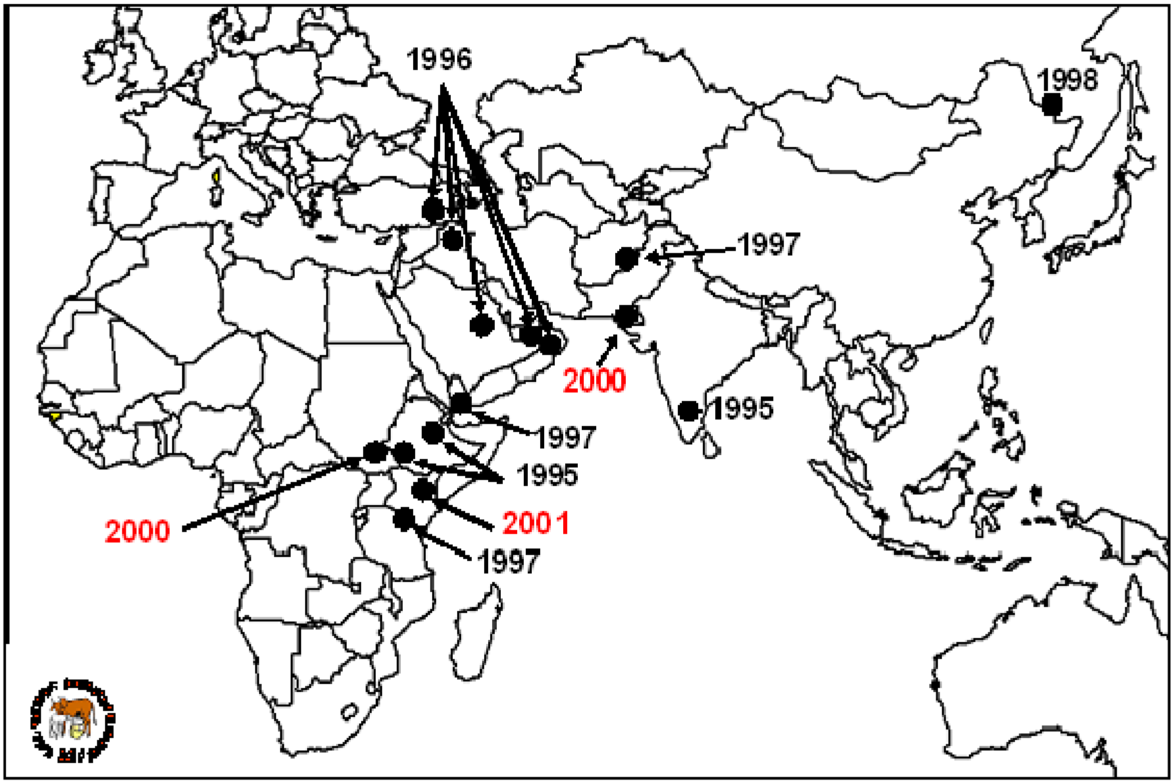
Immediately after the inception of the GREP in 1994, the program undertook a series of epidemiological studies to determine the global extent of rinderpest infection and the means by which it was being maintained. This analysis identified seven areas of concern that could have been acting as reservoirs of infection in 1997 (Figure 4). In 1998, GREP Technical Consultation and EMPRES Expert Consultation meetings in Rome (FAO 1998) advised that the continuing presence of foci of rinderpest persistence could not be regarded as matters of local concern but called for concerted action to eliminate them within five years (FAO 1998). These areas became the focus of a five-year Intensified GREP, which was initiated in 1999 to clarify rinderpest status and eliminate infection if found. The areas to be addressed were southern Sudan, the Somali ecosystem, the Arabian Peninsula, the Kurdish Triangle (Iran, Iraq, and Turkey, actually rinderpest free since 1996), Pakistan with Afghanistan, the southern part of peninsular India (from where the virus had actually been eliminated in 1995) and the adjacent areas of Mongolia, China, and Russia (in none of which was there persisting infection). The PARC largely catered to the African foci but, in Asia, the GREP secretariat had to source funding for, manage, and coordinate the required programs of rinderpest control and accreditation. Although going against its advisory mandate, the GREP secretariat's operation of rinderpest control and surveillance programs in key countries such as Iraq, Pakistan, Sudan, Tanzania, Kenya, and Yemen contributed greatly to the success of the global program. These were conducted with a combination of FAO Technical Cooperation Programme (TCP) funding, donor trust funds, primarily from the EC and the United States, and by incorporating rinderpest control into humanitarian aid programs such as those in Sudan (Operation Lifeline Sudan), Iraq (U.N. Oil For Food Programme) and Afghanistan, linked to supportive FAO Regular Programme funding. These projects were well received by recipient countries with which the GREP secretariat had developed a close and cordial working relationship. Figure 5 indicates the last cases of rinderpest known to have occurred, and illustrates the progress achieved. In fact we can now see that the target of the Intensified GREP was achieved by 2001.

Figure 4. The seven known or suspected reservoirs of rinderpest virus infection in 1996, indicating the lineages of virus involved



Source: FAO GREP.

Figure 5. The last known occurrences of rinderpest since 1995



Source: FAO GREP.

During its evolution as the principal international standard-setting organization, the OIE came to play an increasingly important role in the GREP by publishing guidelines such as those for surveillance and freedom accreditation in association with the Terrestrial Animal Health Code Rinderpest Chapter, as well as the diagnostic and vaccine standards contained in the Manual of Diagnostic Tests and Vaccines for Terrestrial Animals. At all stages of the process, GREP secretariat staff contributed to the formulation of technical guidelines and were active partners in the processes, just as the OIE contributed to GREP technical consultations organized by the FAO. The OIE was also involved with the FAO in the PARC and PACE as members of steering committees and played an active role in guiding strategy decisions. As the GREP evolved and the rinderpest freedom accreditation process became the predominant focus, the OIE assumed responsibility for providing guidelines for application and for policing the accreditation of countries through its Scientific Commission, aided by the establishment of an ad hoc rinderpest group. Now in 2009, both organizations are working toward a joint declaration in 2010 that global freedom has been achieved, an event planned by the GREP since its inception.

7. ACCREDITATION OF RINDERPEST FREEDOM

Unlike with some of the more contentious areas of interaction, the collaboration of the FAO and the OIE in encouraging and aiding national authorities to apply for rinderpest freedom accreditation was exemplary. One of the most difficult elements of the rinderpest eradication process to manage with regard to the verification of rinderpest freedom was making the transition from mass vaccination to surveillance. There is a marked tendency for annual, pulsed vaccination campaigns to become an institutionalized activity. Until the mid-1990s, the global distribution of rinderpest and the relationship of outbreaks to endemic reservoirs were poorly understood. As a result of the uncertainty this induced, many countries sought security in annual vaccination campaigns even if these became increasingly less effective with the passing of time. In retrospect, many countries in Africa and Asia continued to implement annual vaccination campaigns to control rinderpest for many years after it had been eradicated from their territory and the risk of reinvasion had become minimal. The inability to differentiate between antibodies induced by TCRV and the wild virus infection sustained an uncertainty of rinderpest status and, thus, tended to support the continuing use of campaign vaccination , as did a lack of trust and communication among countries on disease status.

PARC-initiated discussions about vaccine withdrawal culminated in the convening of an expert group on rinderpest surveillance systems by the OIE in Paris in 1989. The resulting guidance provided in a document entitled Recommended Standards for Epidemiological Surveillance Systems for Rinderpest were subsequently adopted by the OIE, became part of the Rinderpest Chapter of the Animal Health Code, and were later referred to as the OIE Pathway. In essence, the guidance had laid out a three-step process (provisional freedom, freedom from disease, and freedom from infection), which constituted a series of verifiable epidemiological objectives against which progress towards eradication could be measured over a period of six to seven years from the last case detected, or four to five years from cessation of the vaccination. Most significantly, cessation of the vaccination was integral to the adherence to the OIE Pathway, while completing all steps on the OIE Pathway (disease searches and serosurveillance) was expected to be far less costly than continuing with endless rounds of mass vaccination. This OIE Pathway served very well as a template for countries to follow until 2007, when the accreditation process was amended to a two-year process of surveillance, taking into account the changed global status of rinderpest.

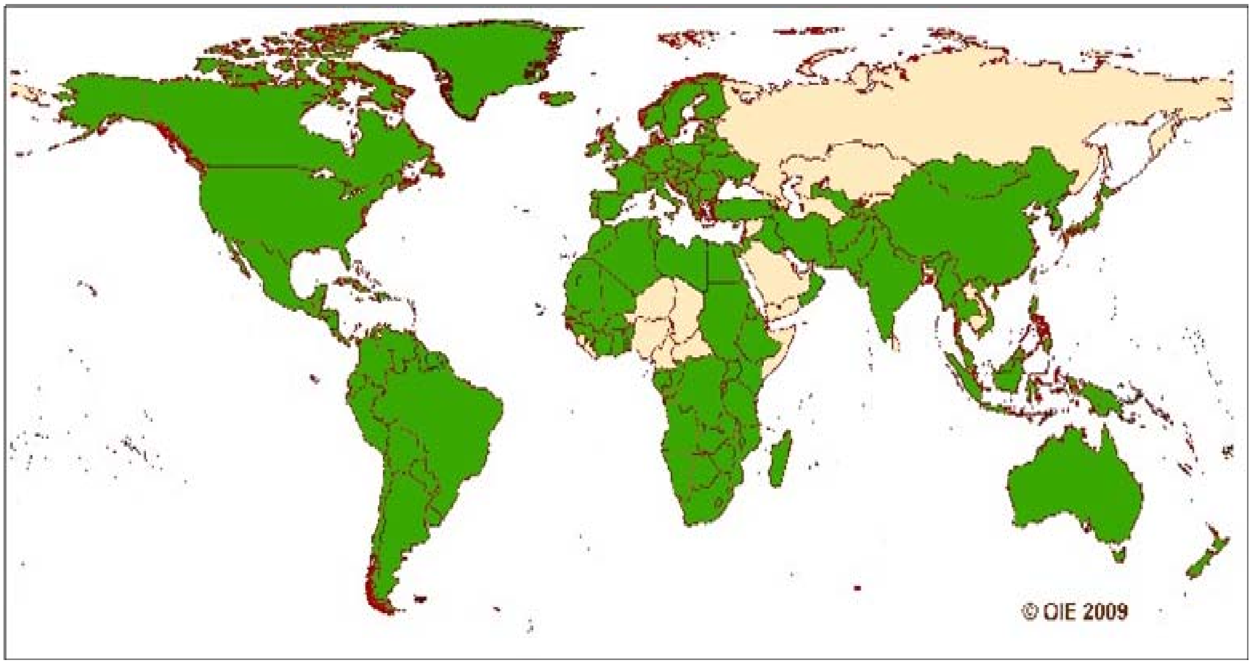
After the inception of the PARC and GREP, rinderpest disease intelligence improved considerably, resulting in a more complete global picture. The communication of risk information through regional fora combined with the promotion of the OIE Pathway gave countries the courage to cease relying on vaccination and begin the verification and accreditation of rinderpest freedom. At last a solution to the terminal problem of JP15 had been found.

Countries were encouraged to manage the cessation of vaccination in an active manner: to cease routine use of vaccination by decree; to subsequently issue a vaccine only in emergencies under direct control of a chief veterinary officer; to withdraw vaccine stocks from the field and secure them in vaccine banks, monitoring their efficacy; and, to withdraw viruses from laboratories and sequester them in a national repository with an inventory.

As success was achieved in clearing countries from rinderpest, the focus of attention rapidly moved away from vaccination to surveillance to demonstrate the absence of infection. Innovative programs were established that combined participatory approaches (Jost et al. 2007) with conventional epidemiological techniques. Increasingly, the accreditation of freedom became the most important action needed and as such, the FAO GREP worked closely with the OIE, becoming increasingly active in encouraging and assisting countries in completing the accreditation process.

Progress in accreditation is illustrated in Figure 6. While the accreditation process is progressing relatively well, as of 2009, the year of this publication, there is cause for concern that the accreditation of all countries individually might not be possible before the end of 2010 if the present process is followed. Rinderpest eradication is increasingly of little interest to countries that have more pressing disease issues to deal with today. Some countries are becoming disinterested in maintaining their free status and the small number remaining unaccredited are proving increasingly difficult to engage in the accreditation process. How this will be resolved is unclear.

Figure 6. Current (May 2009) status of OIE accreditation of rinderpest freedom



Note: Countries accredited as free are colored green; some of the remaining countries are in the pipeline.
Source: OIE (World Organisation for Animal Health).

8. IMPACT OF RINDERPEST ERADICATION

Overview of Previous Economic Impact Studies on Rinderpest

Despite the significant success in the global effort to eradicate rinderpest, surprisingly little information quantifying the scope of these efforts exists, particularly on a global basis. The majority of information that is available tends to be either piecemeal or case-specific, referring to specific outbreaks or control programs. A further weakness in the available information on the economic impacts is that there is a disproportionate amount of information on Africa, despite the fact that parts of Asia (particularly Pakistan, Iran, and India) previously faced significant problems with the disease. A final problem is a matter of data: livestock production data are notoriously unreliable at the national level, while the attribution of production impacts independent of disease-control interventions are problematic at best.

The most comprehensive study on the economic impact of rinderpest was conducted by Tambi et al. (1999) in their evaluation of the PARC. As noted earlier in the paper, the PARC program was implemented in 20 countries in West Africa and 7 countries in East Africa and combined emergency action to control existing outbreaks with a program intended to strengthen veterinary services in the expectation that this would lead to rinderpest eradication. Included within this program was a phased vaccination and surveillance program that aimed to eradicate remaining pockets of the disease. The program began in 1986 in an emergency guise and over the next dozen years was rolled out to gradually control the disease in target countries. Tambi et al. (1999) report total donor funding of the nonemergency phase of the program (198899) at 57.5 million ECU (European Currency Units). The program was extremely successful in West Africa, where it built on national rinderpest control programs supported by the FAO in the wake of the second great African rinderpest pandemic, with the last reported outbreak in 1988, while success in eastern Africa was slower.

The analysis in Tambi et al. (1999) examined the cost-effectiveness of the PARC program in a subset of 10 recipient countries: Benin, Burkina Faso, Cote d'Ivoire, Ethiopia, Ghana, Kenya, Mali, Senegal, Tanzania, and Uganda. The total cost of the PARC program in these 10 countries was estimated at 51.6 million ECU, which included both donor funding and national matching funds. Approximately 123 million cattle were vaccinated, implying an average cost per animal of 0.42 ECU in the 10 regions, though this ranged from 0.27 ECU per animal in Ethiopia to 1.71 ECU per animal in Cote d'Ivoire (Tambi et al. 1999). Leslie and McLeod (2001) estimate that vaccination costs in the PARC program ranged from 5 to 33 percent of the total costs of the program, based on a per unit vaccination cost of US$0.09.

Tambi et al. (1999) subsequently analyzed the costs of the PARC program compared to the benefit derived from it. Their focus was on "avoided losses" generated from the PARC program in terms of the program's influence on improved production in beef, milk, and manure, and services from animal traction. They estimated that the program resulted in avoided losses of 126,000 tons of beef, 39,000 tons of milk, 14,000 tons of manure, and 86,000 hectares of animal traction. It is not completely clear in the study how these benefits were derived. Moreover, the paper seems to only focus on the direct benefits of disease control, omitting important second-round impacts on international trade and other parts of the economy. Thus, it is likely that the benefits attributable to the PARC are understated in their analysis.

The total value of these avoided losses was estimated at 99.2 million ECU, implying a benefit–cost ratio (BCR) of the program of 1.85 (Tambi et al. 1999). Country-specific benefits ranged from a high of 35.4 million ECU in Ethiopia to a low of 0.5 million ECU in Benin, while BCRs in all 10 study countries were greater than 1 (ranging from a high of 3.84 in Tanzania to a low of 1.06 in Côte d'Ivoire). The authors further computed internal rates of return (IRRs) based on the benefit–cost ratios for selected countries, which ranged from 11 percent for Cote d'Ivoire and 118 percent in Burkina Faso, suggesting that the return to investment from the PARC was high relative to alternative uses.

The Tambi et al. (1999) study finally attempted to assess welfare measures from the PARC program based on economic surplus measures (in other words, producer and consumer surplus). The rationale is that the PARC program would lead to a shift in the supply curve for livestock (and products), increasing the quantity supplied and lowering the price. Their surplus measures thus tried to gauge the extent to which producers and consumers gained from the program. Results from their simulation analysis showed that welfare gains from the PARC amounted to 57.5 million ECU, of which 81 percent accrued to producers and 19 percent went to consumers. From a subsector perspective, the overwhelming majority (92 percent) of gains on the production side went to meat production, with the remainder going to milk production. One critique of the surplus measures concerns the (implicit) assumption that beef is a non-tradable product, given that the authors assume price declines from the supply shift in livestock production. However, as illustrated in Sadoulet and de Janvry (1995), supply shifts for tradable goods imply only a production effect since the relevant price is the world price, not the domestic price. A second critique concerns the lack of multi-market impacts from such a shift, notably feed and other service markets.

Most studies do not match the breadth of coverage in the Tambi et al. (1999) study, but a few studies provide insights on the returns from rinderpest control in a benefit–cost setting. Blakeway (1995) evaluated the benefits of rinderpest control in the context of donor-funded UNICEF support to livestock development in southern Sudan. Blakeway assumed that rinderpest control would lead to a 7 percent rise in cattle numbers each year, with benefits from avoided losses in livestock (US$3.8 million) and in avoided food aid needed to replace the lost food sources resulting from rinderpest outbreaks (US$3 million). At a cost of US$200,000 to achieve this, Blakeway (1995) derives a rather high benefit–cost ratio of 34:1[3]. Earlier country-level studies find benefit–cost ratios that were closer to those in Tambi et al. (1999). For example, Felton and Ellis (1978) computed a BCR of 2.48 and an IRR of 48 percent for rinderpest control in Nigeria. An ex ante simulation study from Tambi, Maina, and Mariner (2004) found that intensive mass vaccination programs to control rinderpest in Ethiopia would have a BCR of 5.08, while a combination of intensive surveillance and targeted vaccination would have a BCR of 3.68. The latter program was thought to be more viable, however, given the logistical difficulties in achieving mass vaccination coverage to a level considered necessary to interrupt virus transmission.

Other studies provide insights on the costs of programs or specific outbreaks, but typically do not provide further information. An early study by Leipissier (1971) found costs of the JP15 program in West Africa during 1962–69 of US$16.4 million to vaccinate 33 million head of livestock. Jeggo (2004) reports an oft-cited figure of US$1.9 billion as the cost of a rinderpest outbreak in Nigeria that killed 500,000 cattle, while an outbreak during 1979–83 affected 100 million cattle in Sub-Saharan Africa. Catley et al. (2005) cites FAO estimates that rinderpest control led to an increase in global livestock production of US$289 billion between 1965 and 1998, with benefits to Africa of US$47 billion. Normile (2008) quotes a FAO figure of US$610 million as the global costs of rinderpest control to date. James (1996) noted that about 500 million head of livestock were in rinderpest control areas in the mid-1990s—giving the vaccination to just 20 percent of those animals at US$0.50 per animal would imply annual control costs of US$50 million. Matin and Rafi (2006) estimated that a major impact of rinderpest on Pakistan has been its effects on international trade, particularly to Gulf countries.

While most of the literature has focused on aggregate, macro-level figures, Catley et al. (2005) also point out a number of the more micro-level impacts based on participatory impact analyses of rinderpest control programs in Africa, particularly in Sudan. They highlight the particularly important role of livestock in pastoral settings as a source of wealth and as a means of social cohesion. Citing a study by Okoth, Catley et al. (2005) report a number of positive micro-level benefits resulting from rinderpest control including significant increases in milk production, improved human health, an increase in the population of sheep and goat flocks of 40 percent attributable to the rinderpest control program, and a decline in cattle mortality attributed to the program of 39–72 percent (Catley et al. 2005).

[3] It could be considered that a BCR of 34 in the context of rinderpest control actually may not be that high, given the multitude of household and other non-market effects attributed to its control that the Blakeway et al. (1995) paper attempted to capture. However, this analysis did not capture the variety of non-market costs (transactions costs, organization costs, etc.) associated with the development and administration of the program, both technical and recurrent, that would almost certainly dampen the magnitude of this number. That is not to suggest the BCR would not still be high, but certainly lower than the figure of 34 reported.

Impacts of Rinderpest on Food Security

Rinderpest, like many virulent animal diseases, has many important economic impacts (Rich, Miller, and Winter-Nelson 2005; Perry and Rich 2007). Obviously rinderpest-related animal morbidity and mortality has had the greatest impact on production, as rinderpest is known to kill large populations of afflicted cattle and buffalo. However, as noted earlier in the review, rinderpest also engenders important downstream impacts in the rural economy. In Asia, a major effect of rinderpest was in the disabling or felling of draught animals used for ploughing rice and other staple crops. The impacts related to draught animals infected with rinderpest have not been adequately quantified, but studies from other animal diseases provide salient insights. Perry et al. (2002) determined that had FMD occurred during the ploughing season in a number of villages in Laos, the impacts could have been devastating to the rice economy, from rice planting to the social dynamics concerning hired traction (for example, in-kind rice payments). In pastoral settings, given the importance of livestock as an integral part of livelihoods, the impact of rinderpest can have strong negative effects, particularly on vulnerable households with limited assets or alternatives to livestock production. At the same time, livestock diseases have more nuanced impacts that are often overlooked in policy circles. In particular, given the multitude of linkages in the livestock marketing chain, a loss in animal stocks upstream will lead to a decline in economic activities among linked traders, slaughterhouses, brokers, retailers, and other ancillary support structures in the rural economy. Rich and Wanyoike (2009) found that a recent outbreak of Rift Valley Fever (RVF) in Kenya, a disease that can also be devastating in terms of animal mortality, had large downstream effects on traders and casual workers in local slaughterhouses. A majority of traders depleted their operating capital during trade bans caused by RVF and were unable to resume operations when the outbreak was contained. In addition, many casual workers were idled during the outbreak, leading to a loss of primary income for hundreds, if not thousands, of households, with little in the way of alternative activities to make up for these losses (Rich and Wanyoike 2009).

Analysis of the Impacts of Rinderpest

As noted above, data on the comprehensive scope of impacts related to rinderpest control are relatively limited. By all accounts, rinderpest control was a smashing success, with benefit–cost ratios in some instances exceeding 30 (south Sudan); indeed, in most financial analyses such ratios are rare. However, what is missing is an indication of the broader impacts on rinderpest control on national economies and on poverty alleviation. Given that the overwhelming majority of beneficiaries associated with rinderpest control are livestock farmers, many of whom are poor pastoralist producers, it would seem logical to conceive that the eradication of rinderpest would have strong pro-poor effects. But to what extent, and more importantly, how does the process of disease eradication compare to other potential interventions that could have similar impacts on poverty?

This section attempts to flesh out these issues. To achieve this goal, we provide a comprehensive analysis of secondary, global data on the beneficiaries of control and the overall impact on cattle populations. We then focus on five case studies of rinderpest control—Ethiopia, Kenya, Pakistan, Tanzania, and Uganda—to assess broader, macroeconomic impacts associated with interventions in the livestock (cattle) sector. All five countries have successfully eradicated the disease and reportedly had large, positive benefits from its control. Our analysis uses social accounting matrices (SAMs) developed by the International Food Policy Research Institute (IFPRI) for each country to highlight the economywide linkages between rinderpest control in the livestock sector and its impacts on the broader economy. Moreover, a benefit of a SAM is its ability to elucidate the distribution of household incomes and how different households, including the poor, could benefit from different policy interventions (Sadoulet and de Janvry 1995). A detailed description of a SAM multiplier analysis and references to country-specific multipliers can be found in the annex.

A caveat of the SAM analysis is that it looks at a general intervention in the livestock sector (which could include non-ruminant species that are not impacted by rinderpest) and attributes those impacts to rinderpest control. Moreover, as the SAMs used are calibrated only to data collected after the interventions, it may not accurately reflect specific benefits associated with rinderpest. On the other hand, the SAM analysis illustrates the strength of economic and distributional linkages between the livestock sector and other parts of the economy, and thus captures generally how interventions in the livestock sector (such as rinderpest control) vis-à-vis other interventions might generally impact the broader macroeconomy. As such, the multiplier analysis should be viewed carefully from an impact standpoint, and is better understood in the context of the economic return to general impacts in the livestock sector more than anything else.

Global Impacts of Rinderpest Eradication

In this section, we first attempt to provide an indication of the beneficiaries from rinderpest eradication and an assessment of the impacts rinderpest control may have had on such groups. This analysis is necessarily a bit crude, given that reliable data on cattle and livestock populations are scarce, but at the very least attempts to give some global context to the scope of rinderpest control.

Thornton et al. (2002) attempted to map the distribution of livestock production and human populations in the context of different types of agricultural production systems. The authors provide estimates of populations in South Asia and Sub-Saharan Africa residing in different production areas, including those primarily found in predominately livestock-only rangeland areas. These populations would be overwhelmingly at risk of rinderpest. In 2000, in South Asia, more than 19 million people reside in livestock-dominated zones, while in Sub-Saharan Africa, more than 62 million (nearly 10 percent of the population of Sub-Saharan Africa) were estimated to be in such areas. Globally, nearly 4 percent of the world's population in 2000 resided in areas dominated by rangeland production systems and were particularly at risk to diseases such as rinderpest. At the same time, particularly in South and Southeast Asia, cattle played an important role in providing draught labor for agricultural production, while in India, Pakistan, and East Africa, dairy production from livestock also contributed to household incomes. Both types of systems can be found throughout mixed irrigated and rainfed areas, and thus the total number of households at risk is much higher.

Table 3 attempts to tease out these potential impacts further by summarizing the total number of poor livestock keepers, based on World Bank rural poverty rates and typologies from Livestock in Development (1999), in each of the zones provided by Thornton et al. (2002). In Sub-Saharan Africa, more than 21 million of the more than 62 million people residing in rangeland areas are estimated to be poor livestock keepers, the vast majority of whom would maintain cattle or small ruminants. In South Asia, approximately 5 million people living in rangeland areas are poor livestock producers, representing close to one-quarter of the total population in these areas. Globally, some 41 million poor livestock keepers live in rangeland areas and would be most at risk from rinderpest (or conversely, would benefit the most from its eradication). Naturally, a limitation of this data is that the data do not allow us to differentiate the type of livestock produced in each area, but nonetheless the data provide an indication of the potential numbers of poor stakeholders impacted by this control effort.

Table 3. Poor livestock keepers, numbers and as percentage of population, by production area and region

Region	LGA	LGH	LGT	MIA	MIH	MIT	MRA	MRH	MRT	Other	Total
South Asia	4,831,532 **(25.97%)**	87,651 **(26.74%)**	106,466 **(27.82%)**	47,940,657 **(9.07%)**	18,982,429 **(9.17%)**	122,519 **(10.24%)**	68,872,440 **(23.78%)**	47,637,565 **(24.08%)**	3,196,044 **(24.00%)**	7,354,918 **(9.09%)**	**199,132,222** **(14.89%)**
Sub Saharan Africa	15,170,239 **(36.10%)**	5,507,258 **(32.98%)**	1,140,097 **(35.22%)**	471,820 **(11.44%)**	14,572 **(11.44%)**	249,095 **(11.44%)**	48,335,642 **(30.77%)**	53,079,093 **(28.07%)**	27,896,841 **(30.50%)**	14,162,359 **(11.71%)**	**166,027,017** **(26.48%)**
Total World	28,020,377 **(23.98%)**	7,359,589 **(25.94%)**	5,411,445 **(15.18%)**	55,324,996 **(8.43%)**	35,929,740 **(6.83%)**	11,994,162 **(1.68%)**	136,569,357 **(22.95%)**	160,030,296 **(20.29%)**	68,887,013 **(11.64%)**	46,236,914 **(6.67%)**	55,763,888 **(11.71%)**

Source: Thornton et al. 2002.
Note: Production System

LGA	Livestock only, rangeland-based arid and semi-arid
LGH	Livestock only, rangeland-based humid and subhumid
LGT	Livestock only, rangeland-based temperate and tropical highland
MIA	Mixed irrigated arid and semi-arid
MIH	Mixed irrigated humid and subhumid
MIT	Mixed irrigated temperate and tropical highland
MRA	Mixed rainfed humid and subhumid
MRT	Mixed rainfed temperate and tropical highland

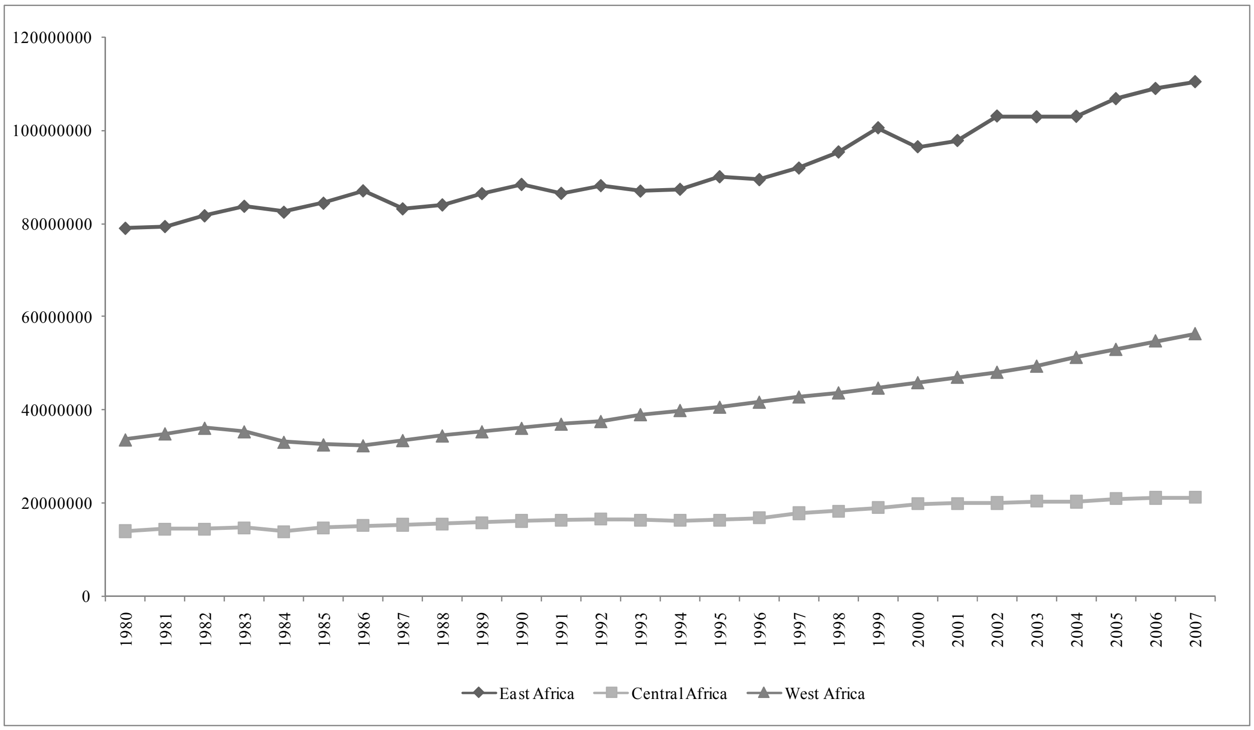
As noted earlier, Tambi et al. (1999) teased out some of the specific benefits of rinderpest control in PARC-impacted countries in terms of avoided losses in the production of beef, milk, and animal traction. A useful, albeit imperfect, indicator of the success of rinderpest eradication is its dynamic impacts on animal stocks and milk production in Africa during the past 25 years. Figures 7, 8, and 9 illustrate a gradual increase in animal stocks and milk production during the 1990s corresponding to the timing of more intense efforts to control rinderpest; the 1980s witnessed relative stagnation to negative growth in livestock numbers (Table 4). Furthermore, in the case of milk, a majority of the increase in production was due to an increase in animals rather than productivity, which was relatively stagnant during the period in question (Figure 9). Similar increases in livestock production were witnessed in Pakistan in the same period (Figure 10), with stagnant production during 1980–95, which rebounded significantly toward the end of the 1990s and early 2000s. At the same time, such growth in livestock numbers in the 1990s still trailed population growth in Africa (Table 5), suggesting that rinderpest control was not sufficient to improve per capita availability of domestic livestock products.

Table 4. Cumulative annual growth rates in livestock inventories, selected regions in Africa, 1980–2005

	1980–85	1985–90	1990–95	1995–2000	2000–05
East Africa	1.10%	0.78%	0.31%	1.16%	1.71%
Central Africa	0.87%	1.55%	0.19%	3.22%	0.97%
West Africa	-0.53%	1.75%	2.00%	2.05%	2.45%

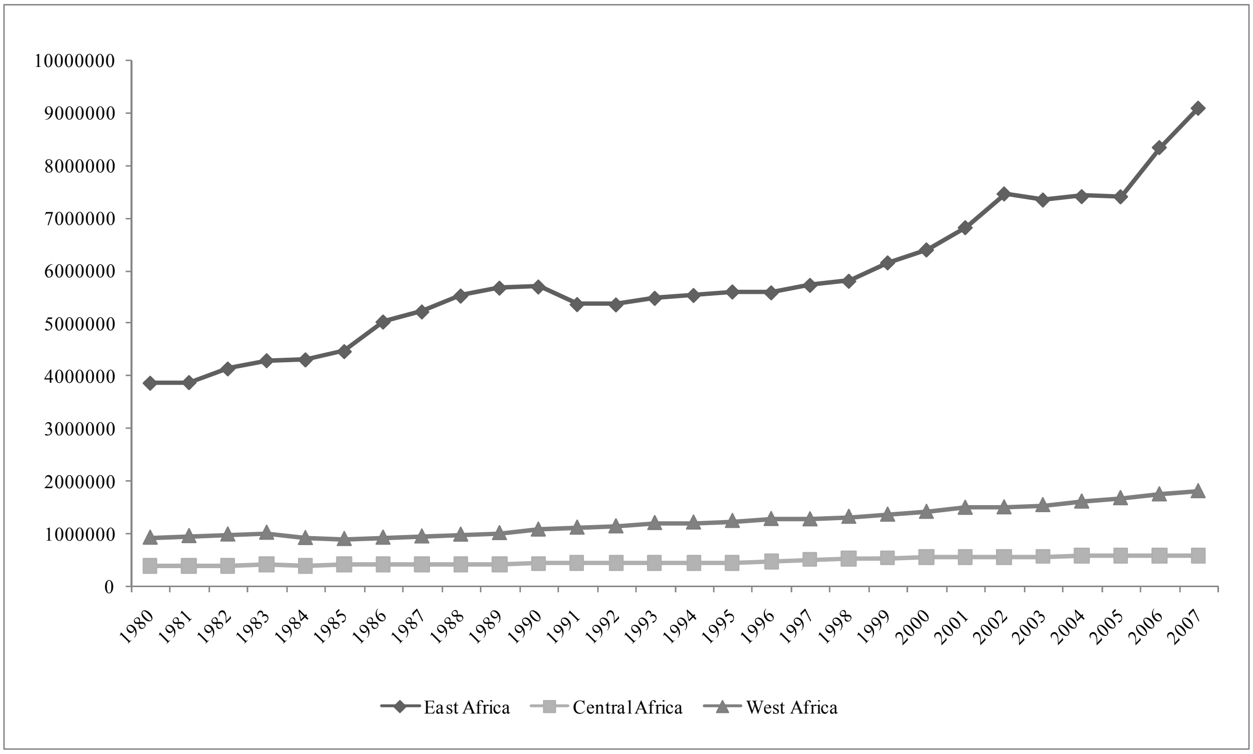
Source: FAO (Food and Agriculture Organization of the United Nations). 2009. FAOSTAT statistical database.

Figure 7. Animal stocks in selected regions of Africa, 1980-2007 (animals)



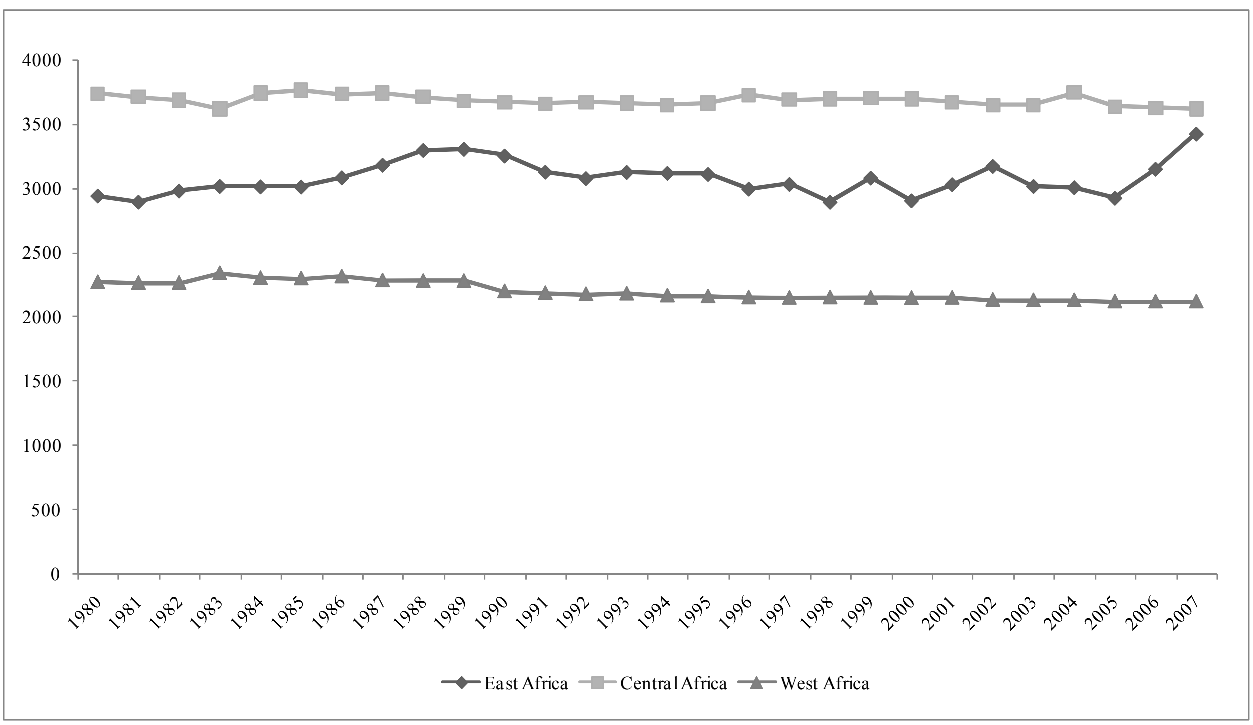
Source: FAO (Food and Agriculture Organization of the United Nations). 2009. FAOSTAT statistical database.

Figure 8. Milk production in selected regions of Africa, 1980-2007 (tons)



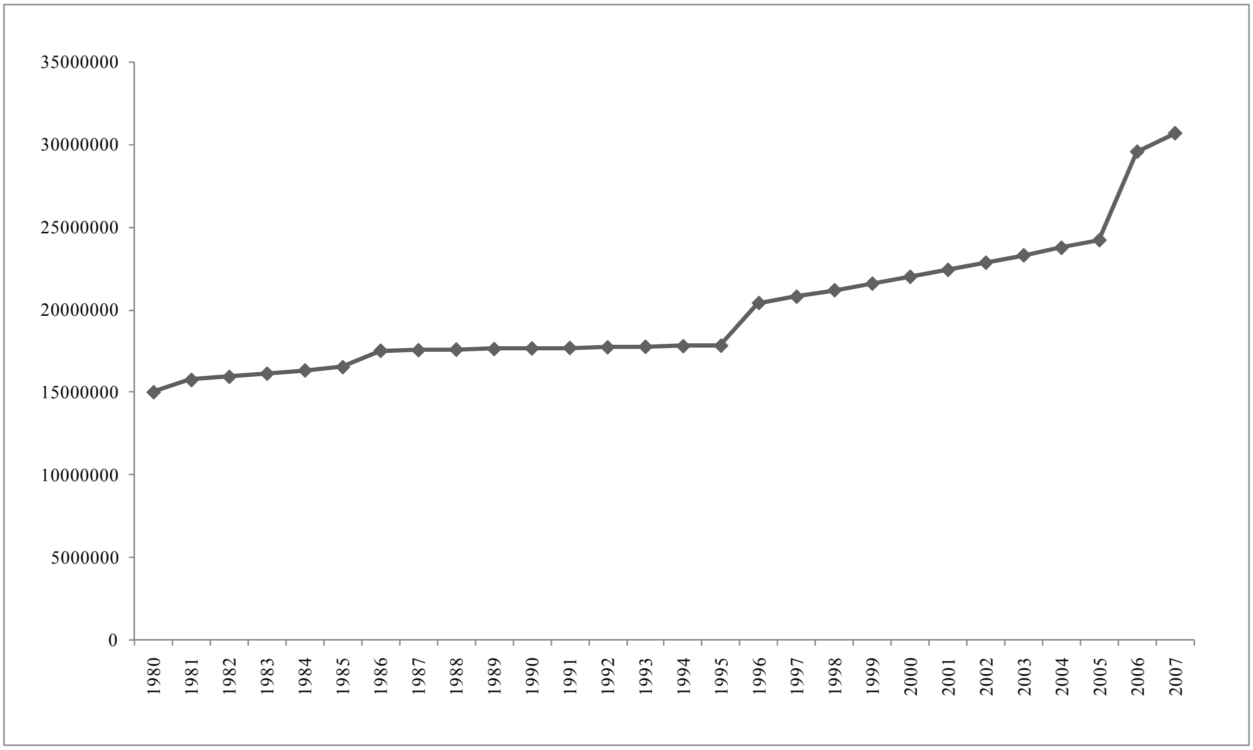
Source: FAO (Food and Agriculture Organization of the United Nations). 2009. FAOSTAT statistical database.

Figure 9. Milk yields per animal (tons/animal) in selected regions of Africa, 1980-2007



Source: FAO (Food and Agriculture Organization of the United Nations). 2009. FAOSTAT statistical database.

Figure 10. Animal stocks in Pakistan, 1980-2007 (animals)



Source: FAO (Food and Agriculture Organization of the United Nations). 2009. FAOSTAT statistical database.

Table 5. Annual growth rates in human population, selected regions in Africa, 1980–2005 (%)

	1980–85	1985–90	1990–95	1995–2000	2000–05
East Africa	2.91	3.01	2.61	2.78	2.57
Central Africa	2.97	3.08	3.43	2.53	2.87
West Africa	2.8	2.73	2.62	2.6	2.54

Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. World population prospects: The 2008 revision. http://esa.un.org/unpp.

SAM multiplier analysis: Ethiopia

According to Tambi et al. (1999), Ethiopia was the largest recipient of PARC funds for rinderpest control, which totaled 14.4 million ECU within a seven-year period, 1989–96 (Table A1). This is not surprising, given that Ethiopia maintains the largest cattle herd in Africa. Based on estimated losses in production, manure, animal traction, and milk, Tambi et al. (1999) estimated that the avoided losses due to the PARC program were 35.4 million ECU. However, if we look at the economywide benefits from the PARC based on the computation of SAM multipliers, the impacts are slightly larger than those found by Tambi et al. (1999). Table 6 summarizes multipliers for activities and households in each of the case study countries, with detailed country-level tables found in the annex. In Table A2, activity multipliers were generated based on a 2005–06 SAM for Ethiopia (Robinson 2009). These multipliers highlight the impact of a one unit increase in final demand on a given commodity sector (as shown in Table A2) on total production in the economy. These demonstrate that livestock has very strong linkages with other productive sectors of the economy. The activity multiplier for livestock was calculated at 3.31, the fourth highest in the Ethiopia SAM, suggesting that changes in spending in the livestock sector will have large effects in stimulating economic growth. Given a total activity multiplier of 3.31, the total economywide impacts of rinderpest control would be 47.6 million ECU—12 million ECU more than the earlier, partial equilibrium estimates of Tambi et al. (1999).

Table 6. Summary of SAM multipliers in study countries

Country	Activity multiplier (rank in country)	Household income multiplier (rank in country)
Ethiopia	3.31 (4)	2.65 (1)
Kenya	2.89 (15)	1.22 (20)
Pakistan	5.18 (5)	2.68 (4)
Tanzania	5.07 (10)	3.13 (10)
Uganda	3.84 (8)	2.96 (7)

Source: Model simulations.

The computation of household multipliers highlights the distributional impacts of injections of government spending, such as those for rinderpest control, into the economy. In Table A3 (and Table 6), total household multipliers were computed that show the impact of a one unit increase in the final demand on a given commodity sector on total household income. Interestingly, livestock has the highest income multiplier among all sectors in the economy, with a one unit increase in government spending yielding a 2.65 unit increase in household income (Table A3). Moreover, if we look specifically at household income multipliers for the rural poor and factor in income multipliers for livestock assets in drought-prone and pastoral areas, we further see strong pro-poor impacts from injections of spending in the livestock sector (Table A4). These findings suggest that rinderpest control potentially had strong poverty reducing impacts, particularly compared to alternative interventions in other sectors.

If we look more closely at income distribution from injections into the livestock sector, we see strong effects in rural areas, with rural groups obtaining 90 percent of the income generated from an increase in the final demand in livestock (Table A5). The rural poor do particularly well, gaining 32 percent of the total increase in household incomes. If we extrapolate the spending from the PARC program in Ethiopia, we find that household income rose by 38.1 million ECU as a result of the PARC, of which 34 million ECU accrues to rural groups, the largest amount in the five study countries (Table 7).

Table 7. Summary of household income gains from rinderpest interventions in the SAM multiplier analysis

Country	Household income benefits from rinderpest-related interventions (ECU)
Ethiopia	38,136,716
Kenya	4,160,782
Pakistan	8,037,227
Tanzania	11,493,353
Uganda	16,021,296

Source: Model simulations.

Kenya

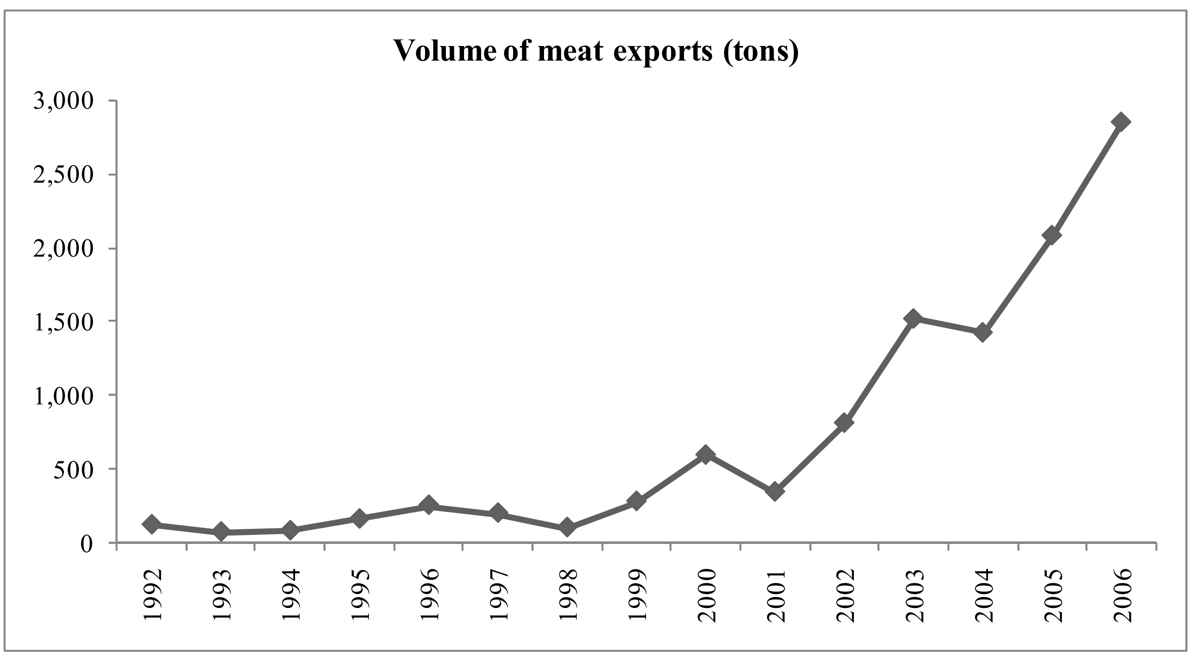
The PARC program's efforts in Kenya were primarily focused on an emergency campaign to vaccinate large amounts of animals after an outbreak was reported in Nairobi National Park in December 1996 (Tambi et al. 1999). As noted in Table A1, Tambi et al. (1999) estimated the avoided losses attributed to these rinderpest control efforts at 4.23 million ECU. While unit costs of the campaign were high due to a variety of logistical constraints, results from the SAM multiplier analysis highlight that its impact on the Kenyan economy was potentially much larger than estimated. Unlike the case of Ethiopia, the cattle sector is relatively less important compared to other sectors of SAM: for instance, the beef sector ranks fifteenth out of the 50 productive sectors in the SAM. Nonetheless, in absolute terms, the multiplier computed for the cattle sector in Kenya (2.89) is still relatively large, so that an increase in government and donor spending on rinderpest of 3.42 million ECU translates into an economywide benefit of 9.88 million ECU (Table A6 Table 6).

Household multipliers in Kenya, by contrast, are relatively small, particularly for the cattle sector. As noted in Table A7 and summarized in Table 6, overall household multipliers for the cattle sector (1.22) rank only twentieth out of the 50 sectors of the SAM, with most primary crop production (other than wheat, rice, and sugar) generating more household income than cattle production. The situation in rural areas is slightly better in a relative sense (eighteenth out of 50), but the total rural household multiplier is just 0.51, less than a quarter of that of Ethiopia. Table A8 reveals the benefits of an injection to the cattle sector (such as from the PARC emergency campaign) and shows that most of the gains overwhelmingly go to urban areas, particularly among higher-income deciles. While stimulating economic activities, the benefits from rinderpest control do not translate as directly into gains for rural households, particularly relative to the Ethiopia case study. Consequently, the potential poverty impacts relative to Ethiopia are much less pronounced.

Pakistan

The case of Pakistan is different from the four African countries considered as case studies, in that it had its own separate control program to eradicate disease. Between November 1999 and June 2005, two separate FAO-led programs spent approximately US$1.8 million on rinderpest control activities. Based on its control efforts, Pakistan was able to declare itself as provisionally rinderpest-free in 2003 (FAO 2003). A major benefit of eradicating rinderpest in Pakistan has been the opening of export markets for Pakistani beef products, particularly to the Middle East, which had banned such exports (Matin and Rafi 2006). Indeed, as illustrated in Figure 11, Pakistan's beef exports increased sharply after 2003, with volumes by 2006 triple those prevailing pre-2003. In value terms, Pakistan's exports of beef products surged from US$991,000 in 2002 to US$2.26 million in 2003 and to US$4.32 million in 2006 (FAOSTAT).

Figure 11. Exports of beef products from Pakistan, 1992-2006 (tons)



Source: FAO (Food and Agriculture Organization of the United Nations). 2009. FAOSTAT statistical database.

Because a source of final demand in the SAM multiplier analysis is export demand from the rest of the world, SAM multipliers are applied in the context of increased exports as a result of rinderpest eradication. Table A9 and Table 6 reveal activities multipliers calculated from a 2001 SAM developed by Dorosh et al. (2003). The activity multiplier for cattle (5.18) is quite large in absolute terms as well as in relative terms within economic sectors of the SAM (fifth out of 33). For instance, the increase in beef exports of US$3 million (roughly the amount of increase between 2002–06) as a result of rinderpest eradication would yield a national benefit of US$15.5 million.

Likewise, as noted in Table A10, household multipliers for cattle are also high, with a one unit increase in export demand for cattle engendering an increase in household incomes of 2.68 units, fourth highest among the 33 productive sectors in the SAM. Much of the benefits from such an injection are captured in urban areas (42 percent), particularly among the urban non-poor (Table A11). However, in rural areas, the largest benefits are captured by small farmers, which combined account for 23 percent of the total household multiplier. Another 14 percent accrues to rural nonfarm (nonpoor and poor) households, ostensibly in wage labor or service industries (Table A11). Given a household multiplier of 2.68, an increase in export demand of US$3 million would raise household incomes by more than US$8 million (Table 7).

Tanzania

Tanzania recorded the second highest estimated benefits in the study by Tambi et al. (1999) of 13.1 million ECU (Table A1) and had the highest net benefits per animal (0.88 ECU). The multiplier analysis with the 2001 SAM constructed by Thurlow and Wobst (2003) suggests that the livestock sector has greater relative (that is, compared to other sectors in the economy) multiplier effects compared to Kenya, but fewer than Ethiopia. As noted in Table A12 and Table 6, the multiplier for livestock ranked tenth out of the 43 sectors in the SAM. However, the magnitude of the livestock multiplier is nearly twice that of Ethiopia (5.07), implying that government and donor spending on rinderpest control of 3.67 million ECU would generate more than 18.6 million ECU in economywide benefits, more than the 13.1 million ECU benefits originally reported by Tambi et al. (1999).

Household multipliers in Tanzania are also quite sizable, particularly for livestock. Tables 6 and A13 show that the total household multiplier attributed to a one unit injection of final demand in livestock would yield an increase in household incomes of 3.13 units, of which 2.34 units would be retained in rural areas. Based on PARC expenditures of 3.67 million ECU, household incomes would rise by almost 11.5 million ECU. The poorest rural groups gain approximately 16 percent of the total rise in household incomes, while non-poor groups gain nearly one-half (48 percent) of any rise in spending (Table A14 and Table 7).

Uganda

Uganda spent the second highest amount on PARC-related expenditures (5.4 million ECU), based on Tambi et al. (1999). However, the return of 10.4 million ECU estimated by Tambi et al. (1999) is one-half that revealed by the multiplier analysis, as shown in Table A15 and Table 6. The multiplier for livestock in Uganda of 3.84 suggests that an increase in spending of 5.4 million ECU would increase economywide output by 20.7 million ECU, second only to Ethiopia in the four African cases considered. The relative ranking of the livestock sector compared to other sectors (eighth out of 26) suggests important economywide linkages of the livestock sector, particularly given that the multiplier figure is just 0.04 below the second ranked sector (Matoke).

Household income multipliers for Uganda are also sizable, as noted in tables 6 and A16. A one unit increase in final demand increases the total household income by nearly 3 units, of which 2.44 units remain in rural areas. Given expenditures of 5.4 million ECU, total income generated from such an injection would raise total household incomes by 16 million ECU (tables 7 and A17). Twenty-one percent of this income would go to regions 3 and 6 in rural areas, which are both considered low-potential regions

(Dorosh and El-Said 2004). An additional 18 percent goes to rural nonfarm households, including wage labor and service providers.

Summary: Economic Impacts of Rinderpest

The above analysis suggests that investments in livestock, such as rinderpest control, have strong, positive economic impacts that spill over into other sectors and, while somewhat variable by country, are pro-poor in nature. Relative to other types of policy interventions, investments in the livestock sector tend to provide more benefits than other interventions in rural areas. Because food security impacts a host of actors throughout the marketing chain, an important consequence of rinderpest control has likely been a general increase in food security in rural areas, and not just among farmers. Relative to rinderpest control investments, while gains on a per household basis are relatively modest, the analysis presented above is static and does not consider second-round impacts on households derived from gains in income attributed to rinderpest control.

9. SUSTAINABILITY OF RINDERPEST ERADICATION

Arguably the global eradication of a disease agent should be the most sustainable of interventions for once extinct it should not be able to return. However, that scenario might not necessarily be quite the case as experience from the Smallpox Eradication Programme has shown. It is difficult to persuade countries to destroy their virus stocks; even international conventions ratified by all countries have not been sufficient to do so even for the officially held stocks.

If the rinderpest virus has ceased to circulate in the domesticated cattle, buffalo herds, and wild ungulates of the world that once served as its natural hosts, one has to ask if there is a risk that the disease could come back and how that could happen. There are several possibilities:

Re-Emergence of Infection from a Wildlife Reservoir

The only populations potentially capable of harboring rinderpest today are the wild ruminants of eastern Africa, but even these relict populations are now so fragmented and reduced in size that they are unlikely to maintain rinderpest for any great length of time as was observed in the Kenyan outbreaks from 1993 to 1996 (Kock 2006). Neither the rinderpest virus nor seroconversion of wild ruminants have been detected in East Africa since 2001, in sharp contrast to the situation during the 1990s; only old animals are seropositive. These findings, combined with earlier indications that rinderpest does not persist indefinitely in wildlife once the disease is eliminated from cattle (Taylor and Watson 1967), are strongly indicative that there is no wildlife reservoir of infection.

Reversion to Virulence of a Live Vaccine

Should live attenuated vaccines be used there will always be the attendant risk of reversion to virulence. Fortunately, the routine use of rinderpest vaccination has reduced dramatically and progressively in the last 10 years and today in 2009 we can be confident that vaccines have not been used for several years. Vaccine producers have largely ceased to make the rinderpest vaccine and stocks are dwindling.

The Presence of an Occult Reservoir of Infection

Rinderpest virus has not been detected in Asia since 2000 and in Africa since 2001 and there is no reason to suspect its presence anywhere. The OIE rinderpest freedom accreditation process provides scientific surveillance-based assurance that countries are indeed free from rinderpest and the global process has proceeded apace. Even the few countries that have not formally applied for accreditation are known to have conducted surveillance sufficient enough to detect infection were it to be present, and received negative results. The likelihood that there still exists a rinderpest reservoir is vanishingly small. In contrast to earlier experiences, rinderpest virus upsurges have not been a feature of any military campaigns fought and resulting civil disturbances in recent years despite ample opportunity for this to happen, contributing to growing confidence that rinderpest has ceased circulating. Nevertheless countries still need to be vigilant about the potential re-emergence of rinderpest until a credible global freedom accreditation process is complete.

Malicious Reintroduction or Injudicious Use of the Rinderpest Virus—Agro-Terrorism and Misplaced Scientific Curiosity

While stocks of virulent viruses remain in the freezers of laboratories around the world, the risk of their malicious use remains. Even if the rinderpest virus is not a very attractive candidate, scientists could be tempted to conduct experiments with the live virus without adequate biosafety. There is an urgent need to undertake an exercise to catalogue and sequestrate viruses to prevent the malicious or injudicious use of rinderpest viruses, and this is being addressed by the FAO and OIE.

Synthesis of Rinderpest Virus De Novo

In the twentieth century, with the spectacular advances of molecular biology, it is no longer necessary to have access to a virus; a blueprint is all that is needed. It is theoretically possible for the rinderpest virus to be recreated de novo from the full virus genetic sequence information, which is freely available. How the world will cope with this risk is not clear.

Reconstruction of the Rinderpest Disease in Cattle with another Morbillivirus.

There are a number of morbilliviruses related to the rinderpest virus that could conceivably enter cattle and evolve to reconstruct rinderpest or something similar. Peste des petits ruminants virus is the most likely candidate but although infection has occurred in cattle with significant prevalence in Asia and Africa for many years, there has never been any evidence for it evolving into a cattle disease agent. However, the risk exists and guarding against it needs to rely on strengthening the world's capacity for early warnings to detect epidemiologically significant events and rapidly take action when detected.

10. LESSONS LEARNED FROM GREP AND RINDERPEST ERADICATION IN GENERAL

The conduct of campaigns over the decades has provided many salutary lessons as to how and how not to conduct large-scale disease-control and eradication exercises. While the biology of diseases and hosts impacts the design of control methods, common threads exist. The rinderpest eradication strategy evolved progressively from annual, institutionalized, pulsed vaccination campaigns to a process of seeking active infection, containing and eliminating it based on a sound epidemiological understanding of the disease behavior, and then confirming the absence of the rinderpest virus. These lessons learned, if acted on, could prove to be a most significant outcome and act as a model for other endeavors in animal disease control. To be successful, experience has taught that a number of prerequisites for disease-control and eradication programs must be considered. The most important issues are described here, and these fall into two broad categories:

Organizational and Institutional Elements

a. Political will, social motivation, and a concerned and supportive international community informed by socioeconomic appraisals of disease impact and eradication.

   Political support is needed at national, regional, and global levels and is an essential prerequisite. Without political commitment, progress is unlikely to be sustained, especially when disease impact diminishes with time. Politicians need to be persuaded of the economic and social benefits accruing if they are to be supportive. As described elsewhere in this paper, socioeconomic appraisal was not given adequate attention during the various programs implemented over the years and for rinderpest, this deficit later constrained the sourcing of funds in what is a very competitive field related to rural livelihood development. In the modern era with many different agendas competing for funding, proposals from animal health technical personnel cannot hope to compete with proposals from economists and social engineers unless they are supported by socioeconomic appraisals of disease impact and the conjectured benefits of interventions. It is also clear that insufficient attention was paid to exploring the attitudes of livestock owners. The argument for a disease-control and eradication program needs to be compelling enough for people living in the areas where operations might take place to support it. Animal owners will not comply with disease-control provisions unless they have a personal stake in the outcome and are committed to it. Only political and social good will and commitment will sustain a program, which will inevitably need to continue for a considerable amount of time.

b. The need for an international coordinating body hosted by an international organization that is mandated to provide technical leadership to regional campaigns and global coordination to be adequately funded.

   It seems important that one organization should take the lead, but this approach will not necessarily work smoothly. Donors funding disease-control programs will overtly welcome this lead, yet these funding bodies tend not to adhere to all decisions reached in a consultative strategy setting and often wish to provide their own orientation to constituent programs, based on alternative priorities that include broader political objectives.

   For instance, starting in 1993 the FAO was mandated by the agriculture ministers of its member countries to take on the coordination role for the GREP, and provided the basic funding necessary for the secretariat to function. Hosting international fora for information exchange (FAO Technical Cooperation Programme participants and Expert Consultations for example), progress monitoring, and strategy setting were particularly valuable activities. However, because regional campaigns did not develop as originally anticipated (see point [d.] below) the GREP secretariat had to assume a greater executive role in implementing control programs than originally contemplated and this stretched resources to the limit. The funding to implement field programs was particularly deficient, in part because of the reluctance of some donors to channel their assistance through the FAO even though they were themselves less than speedy in setting up rinderpest control programs.

c. The need for a program to be time-bound and objectives-focused, realistic, and clearly expounded and implemented with a gated management approach.

   Before embarking on control programs, a preparatory phase needs to clearly describe the implementing mechanisms that affect disease control and identify a minimal package of capacity development. Attention must be given to such issues as the capability and capacity of the relevant arm of veterinary services of targeted countries, vaccine delivery systems, and policy issues such as cost recovery and legal provisions. An initial lack of technical support for operations need not necessarily prevent initiation of a program but the deficits need to be clearly understood and urgently addressed once a program starts.

   Confusion about objectives can be problematic. For example, the need to enhance capacity for the control of a specific disease and maintain a primary focus on rapid disease elimination can be distracted by broader infrastructure and capacity development objectives. Most technical personnel will wish to stay focused on the prime objective while others will want to exploit the disease-control initiative to address longer term development concerns by tying this initiative to such issues as privatization and decentralization of veterinary services and even broader political objectives such as governance and human rights. Experience teaches not only that disease control progresses more rapidly in focused programs than in broadly based programs but also that capacity development is best addressed through a specific, focused program.

   The availability of resources for a disease-control program can attract those with alternative disease-control agendas. For example, although both programs were ostensibly focused on rinderpest eradication, the PARC came to devote a significant part of its resources to CBPP control and evolved into PACE, which focused to a considerable extent on generic "epidemio-surveillance systems" as well as CBPP control. Disease-control programs often need to address supplementary disease issues, but this is a different issue from deviation from objectives. An example from Pakistan concerns rinderpest and PPR where differential diagnosis can be a problem and the same vaccine was in use for both diseases. In order to cease use of rinderpest vaccination for the purposes of rinderpest freedom accreditation, it was necessary to provide an alternative PPR vaccine for use in small ruminants. In the case of FMD control, it is advantageous to address hemorrhagic septicaemia control for buffaloes in South-East Asia because deaths from the latter tend to discredit the process of vaccination in general and reduce farmer compliance with program strategy.

d. Regional organizations capable of coordinating regionalized control campaigns and accreditation of disease freedom committed to working closely with the global coordinating body. Global campaigns are too large to be operated by a central unit and are best addressed through manageable regional groupings of countries, each of which needs to be coordinated by a credible regional organization. Although the FAO and partners formulated the concept of a number of regional campaigns to promote the GREP, in reality it was only the African region that assumed responsibility through the PARC and PACE. Inevitably to safeguard the program, promoting rinderpest eradication in areas of the world and countries not covered by regional campaigns became the direct responsibility of the GREP secretariat, which was not set up nor really equipped for this purpose. Regional coordinating bodies need to assume primary responsibility for the conduct of programs, monitoring progress in control and accreditation of disease freedom on a regional basis. This approach has the added advantage that countries represented on a regional accreditation working group are more likely to develop “ownership” of the accreditation process and peer pressure could be brought to bear on intractable countries.

e. Dynamic, adaptive, and technically oriented leadership and management with a global perspective.

   Generally speaking, financial managers require performance targets to be set well in advance and the success of a program is usually judged on how well the targets are reached. In rinderpest eradication, this approach was a problem primarily, but not exclusively, at a national level with respect to vaccination targets. Vaccination performance is relatively easy to monitor in terms of numbers of vaccinated cattle, yet the aim of a control program needs to be to move away from mass vaccination as soon as it can be determined that the virus has ceased to circulate in zones or countries. The criteria by which performance should be monitored must therefore be orientated towards progress in achieving this goal rather than vaccination performance, however difficult and demanding this might be. The points at which the mass vaccination and focused vaccination or no vaccination transition need to be made cannot be set accurately in advance and depends on real-time monitoring of virus circulation. Management must be output-orientated rather than process-orientated.

   Leadership of a disease-control program at national and regional levels requires skills and experience in both program management and population medicine. It is unrealistic to expect one person to cover both areas adequately but too frequently this has been the case and the planning, financial, logistical, and reporting issues have tended to overwhelm the innovative technical inputs needed.

Technical Elements

a. A clear and evolving understanding of the epidemiology of the targeted disease.

   At the inception of the GREP, there was no clear picture of where rinderpest was occurring in the world nor of the factors involved in virus maintenance and propagation. Once the geographic extent of rinderpest infection was established—and it was recognized that relatively discrete reservoirs of infection acted as the source of visible epidemics in normally unaffected populations—then it was possible to set a strategy for the progressive elimination of infection. Each disease will present its own challenges but there are bound to be important deficits in understanding at the start of any control and eradication program and it is essential to anticipate the need for a mechanism to provide epidemiological information. This need is closely linked to that of laboratory diagnostic support. Epidemiological expertise applying all the available tools of surveillance and data analysis by temporal and spatial mapping within a geographical information system environment is fundamental to effective disease control. For example, mathematical modeling, both deterministic and stochastic (Tillé et al. 1991; James et al. 1989; Rossiter et al. 1989; Mariner et al. 2005), assisted in setting the strategy for elimination by providing insights into the importance of stochastic factors in rinderpest ecology, which contributed significantly to the understanding of virus persistence.

b. Safe, efficacious, affordable, and quality-assured vaccines (preferably thermostable and marked vaccine matched with discriminatory serological tests).

   The setting of procedures for the quality assurance of rinderpest vaccines and the establishment of a facility in Africa where vaccine assessment and certification could be performed made an invaluable contribution not only to the PARC and PACE but also to the GREP outside Africa through services provided to campaigns in other countries, as mentioned earlier. The PANVAC was established and run for some years by the FAO as a service to the AU IBAR for the PARC. It had a troubled history with periodic serious funding deficits but managed to provide an almost continuous service and to generate income from vaccine testing. The service now institutionalized within the AU IBAR has the potential to be used for other vaccines, essentially for Africa. No other independent vaccine quality-assurance facilities in Africa or elsewhere exists for other vaccines. This is a serious deficit that constrains FMD control, for example, because countries are unable to monitor independently the quality of vaccines that they purchase for their use.

Vaccines that might be fit for use in temperate, developed country environments are not necessarily fit for use in tropical and remote environments. The seminal research that led to the provision of a thermostable rinderpest vaccine made a very significant contribution to rinderpest eradication from remote areas in Africa and in several Asian countries. Vaccines need to be fit for purpose, and robustness in terms of thermostability is an important attribute for all vaccines if they are to be used in developing countries. Research is required to engineer thermostable vaccines for use in such environments. In addition, a means needs to be found to provide vaccines in small-dose vials for the village environment. A lack of small-dose vials certainly reduced vaccination efficacy in rinderpest vaccination campaigns as the vaccine rapidly loses efficacy once reconstituted.

c. A set of robust, validated laboratory diagnostic tools for agent detection (including a rapid pen-side test) and serology to support rapid diagnosis and surveillance, together with a technology transfer process incorporating quality assurance.

Tests used need to comply with OIE standards to support OIE country disease reporting obligations and freedom accreditation procedures. Ideally the technology adopted should be fit for purpose in countries without sophisticated diagnostic facilities; such techniques as filter paper sampling, for example, can be valuable in developing world environments, but there is little incentive for these to be developed for highly developed countries. Support for the development of appropriate diagnostic techniques needs to be built into programs.

Rapid pen-side tests for rinderpest proved valuable in searching for the virus, especially in Pakistan, where their provision empowered field veterinarians to be more definite about disease suspicions and report them. They also facilitate definitive laboratory confirmation by indicating which animals are likely to be good sample donors. Such tests are now becoming available for a range of other diseases, such as FMD for example, and can facilitate field-control programs especially when disease incidence has been greatly reduced, as in the final stages of an eradication program.

One issue that has caused serious problems in rinderpest infection monitoring and freedom accreditation is the inability to discriminate between antibodies induced by vaccination and wild virus infection. Validated discriminatory test systems were never made available and, thus, considerable time had to pass after the cessation of vaccination for a cohort of animals to develop so they could be studied. Seromonitoring of vaccination programs would have been facilitated and freedom accreditation could have proceeded much more rapidly had such a vaccine test system been available. Similar problems have been encountered, inter alia, with avian influenza, Newcastle disease, peste des petits ruminants and classical swine fever control programs.

d. A world and regional reference laboratory network supporting the technology transfer to national diagnostic laboratories and technical fora for information exchange.

The designation and provision by the FAO of limited support to the U.K. Institute for Animal Health, Pirbright Laboratory, to function as the World Reference Laboratory made a significant contribution to supporting national and regional control programs. The laboratory's scientists made important contributions in developing diagnostic tests and technology transfers, providing reference diagnostic services, establishing molecular epidemiology, providing vaccine quality assurance, training operational staff, and developing training materials. Such services are indispensable in disease-control and eradication programs. Regional reference laboratories were somewhat less operationally successful partly because, in general, they lacked enough resources to provide the services required at the regional level. Ideally a network is needed to bring together national laboratories supported by a regional laboratory, and regional laboratories supported by a global reference laboratory.

The transfer of technology to national and regional laboratories is an essential activity in any control and eradication program. In the case of rinderpest, the FAO/IAEA Joint Division played a significant role in harmonizing diagnostic technology—technology transfers to laboratories that were engaged in regional laboratory networks in Africa (for the PARC) and West Asia. Similar arrangements, as also initiated by the Joint Division for FMD, are needed if other control and eradication programs are envisaged.

e. Dynamic and innovative disease-control and eradication strategies based on epidemiological studies, adapted to local conditions and amended repeatedly.

Control and eradication planning must be a dynamic process that evolves as situations change; strategy set for the long term will inevitably need to be modified in the light of experience gained. This is especially so as the goal of eradication approaches.

The strategy set needs to pay due attention to the needs of livestock owners relative to differences in farming systems and their socioeconomic status; it is essential that they are consulted (Mariner et al. 2002). In Ethiopia, for example, vaccination coverage in the Afar region, which constituted a long-standing reservoir of rinderpest, was initially poor during national programs as well as the JP15 and the PARC. Central planning of vaccination campaigns failed to place vaccination teams at sites amenable to pastoralists and insistence on vaccinating all ages of cattle, which the pastoralists knew to be unnecessary, antagonized them. Once due attention was paid to the livestock owners' wishes regarding sites and practices for vaccination—and this was combined with community-based animal health worker programs in remote areas along with use of the thermostable vaccine—herd immunity was raised to a level where rinderpest was quickly eradicated. One lesson from this is that vaccine delivery strategies need to be modified according to the needs of the livestock owners and defined for different livestock populations.

f. A clearly defined disease freedom accreditation process.

From the start of the GREP it was envisaged that the OIE would take responsibility for operating the rinderpest freedom accreditation process, which it did by developing with partners the OIE Pathway and managing the certification process. Stringent conditions for accreditation were set and slow but steady progress was made in accrediting countries as free from rinderpest disease or infection. The goal for global rinderpest eradication of 2010 was selected at the outset as a reasonable prospect and having this tight schedule proved very valuable to guide progress along the OIE Pathway. Although it is now considered likely that rinderpest ceased to circulate in both domesticated and wild animals by 2001, it is a salutary lesson that after eight years of rinderpest freedom, still no declaration of freedom has been made. It is not clear now why every single country needs to be individually and formally accredited as free from rinderpest nor how intransigent countries are to be coerced into undertaking the accreditation process. The process can involve considerable expense and is not attractive to countries that no longer consider rinderpest a threat and do not trade in livestock to any significant extent. Also, opinions differ as to whether a global declaration needs to be linked to the cataloguing and sequestration of viruses, as it now is. Proving global freedom from an animal disease is only now being undertaken for the first time and the processes involved, although clearer than before, are still not fully defined. In any future eradication program, the final accreditation process and the manner in which an announcement of global eradication is to be made, needs to be clearly defined in advance.

11. CONCLUSIONS

The eradication of rinderpest was achieved progressively by national control programs organized within a series of intermittent, concerted international efforts during a period exceeding 50 years. Should the rinderpest disease become trivialized from our current perspective, we ought to consider the damage that the disease caused in countries such as India, Pakistan, Afghanistan, Kenya, Ethiopia, Turkey, Iran, Oman, United Arab Emirates, and Saudi Arabia in the last 20 years. It is testimony to the progress of the control effort that its impact has been so muted in recent years.

Clearly, the eradication of rinderpest, now almost certainly assured, has been a remarkable achievement that has brought major benefits to human populations in the developing world, even though financially these might be difficult to define precisely. The analysis presented here suggests that the benefits accruing from the financial inputs made into rinderpest control include strong positive economic impacts that can be considered pro-poor in nature with rinderpest eradication leading to a general rise in food security in rural areas. In addition, but very important for a considerable number of countries, a growing appreciation that rinderpest has been eradicated has started to result in increased financial returns on trade for a number of countries despite the continuing presence of other diseases that constrain trade, such as FMD.

The legacy of rinderpest eradication includes not just the beneficial impact on affected livelihoods of removing this devastating disease, but also improved animal health delivery systems for marginalized communities, disease surveillance and control techniques, and participatory epidemiology, operating where conventional data sources are limited. The programs implemented for rinderpest eradication at the national and regional levels helped to strengthen the surveillance and disease-control capacities of many countries. Even if the infrastructure developed is only temporary, the experience gained has significantly improved the tools available for veterinary disease surveillance and control. We should also not forget that the removal of rinderpest provides a safeguard for the wildlife heritage of African countries primarily but in the Middle East and Asia as well.

Despite the evident constraints, eradication of an infectious disease is clearly feasible provided that a set of technical tools are available and the political and social will to proceed at both national and international levels exists. However, the decision to embark on another major disease eradication program must be informed by the experiences gained during the rinderpest eradication effort, coupled with a realistic consideration of whether funding and a commitment can be maintained within the agreed-upon timeframe. These considerations extend well beyond the purely technical issues. There is an ongoing debate about whether campaigns to eradicate disease are the most appropriate way to deal with the risks posed by especially dangerous pathogens with epidemic and pandemic potential. To an extent, opinions depend on whether one's perspective is that of a western country, with industrialized livestock production systems that are essentially free from epidemic diseases, or that of a developing nation that is very highly dependent on livestock production for livelihood generation and subsistence. The developing concept of commodity accreditation (Thomson et al. 2009) to support trade suggests that trade in livestock products need not necessarily depend on area-wide disease eradication, therefore eradication of a trade-related disease could become irrelevant; yet this assertion does not take into account the impact of the disease on livelihoods in livestock-dependent areas of the world. Perhaps a combination of approaches is more effective than global eradication campaigns: regional ecosystem-defined, progressive control programs within groups of the least developed countries, which act as persisting reservoirs of infection, combined with other processes of risk management in trade. Over time, the end result could be the same since the havens for epidemic livestock diseases lie primarily within the poorer areas where livestock are essential for food production and rural livelihoods.

ANNEX: TECHNICAL DETAILS OF SAM MULTIPLIER ANALYSIS

Overview of SAM Multiplier Analysis

Input-output (I-O) models have a storied history in economic analysis. The basis of I-O analysis is the input-output table, in which economywide transactions of productive sectors are recorded (at varying levels of aggregation, depending on data availability). The rows of an input-output table represent the sales or income generated by one sector from other sectors, while the columns detail the payments or purchases made by a sector to other sectors. Input-output tables also contain information on the value-added generated in an economy (this typically includes salary and tax payments) and final demand resulting from household consumption, investment, government spending, and net exports (Miller and Blair 1985; Sadoulet and de Janvry 1995). SAMs expand upon this information by specifying different types of factor accounts and households that interact in the economy. In many cases, household accounts are disaggregated spatially (urban and rural or by specific regions in the country) and by income class (poor and rich at a minimum, with some SAMs elaborating on income quartiles or deciles) (Kiringai et al. 2006).

Input-output tables can be used to detail the linkages between productive sectors in the economy and to assess how changes in final demand influence each sector. One means by which to do this is through the calculation of I-O multipliers. Define **A** to be the matrix of fixed input-output coefficients from productive sectors. The elements of the **A** matrix, a_{ij}, are the technical coefficients of sector i's use of input j and are calculated by dividing the *ij*-th entry of the input-output table by output in sector j. Let **X** be the vector of final demand and **y** the vector of output for sectors 1 through n. Then, the I-O table can be rewritten in matrix form as **Ay** + **X** = **y**, or **(I-A)y** = **X**. To obtain output multipliers, one needs to solve the previous equation with respect to **y**, which provides the standard Leontief inverse matrix, that is:

$$y = (I - A)^{-1} X \tag{1}$$

In equation (1), the multiplier matrix, $(I\text{-}A)^{-1}$, details the total change in output in sector j resulting from a change in final demand for the output of that sector (Miller and Blair 1985). The total output multiplier (in other words, the direct and indirect effects on other sectors) is computed using the column sum of the a_{ij} terms.

Income and employment multipliers can also be determined through a like process. The income multiplier from a change in final demand in sector j is the sum of the product of the household income received from all productive activities and the technical coefficient, a_{ij}, meaning:

$$H_j = \sum_{i=1}^{n} a_{n+1,i} a_{ij} \tag{2}$$

Income multipliers can be transformed such that they measure the effect of a change in payments to households; these are termed "Type I" multipliers and are obtained by dividing equation (2) by a household's income from sector j. Employment multipliers are analogous to income multipliers, but involve the technical coefficients for labor rather than households. One often finds in the literature mention of "Type II" multipliers; these refer to multipliers in which households (or labor) are endogenized into the A-matrix and thus tend to lead to larger multipliers than Type I multipliers. SAM multipliers treat factors of production and households as endogenous accounts and are part of the A matrix above. Consequently, SAM multipliers tend to be larger than conventional I-O multipliers (Sadoulet and de Janvry 1995).

As noted above, changes in the output of a sector arise from exogenous changes in final demand, which can come from an increase in export demand, government spending, or private investment. Consequently, the impact of the PARC program on the broader economy in a given country can be estimated simply by deriving Leontief multipliers and multiplying these by the expenditure from the

PARC on that country (Table A1). The result provides the direct, indirect, and induced effects of the PARC program on the economy itself. Unlike the analysis of Tambi et al. (1999), SAM multipliers provide a much more complete picture of the changes in national output (not just in the livestock sector itself) potentially engendered by disease-control programs and, more saliently, allow us to explicitly tease out the potential poverty impacts of such programs as well.

ANNEX TABLES

Table A1. Expenditures and benefits on rinderpest control under PARC in case study countries

Country	Years of expenditure	Expenditure (million ECU)	Net benefit (million ECU)
Ethiopia	1989–90 – 1995–96	14,388	35,433
Kenya	1997–98 (emergency funding only)	3,422	4,227
Tanzania	1992–93 – 1996–97	3,672	13,127
Uganda	1991–92 – 1996–09	5,404	10,418

Source: Tambi et al. 1999.

Table A2. Activity multipliers from the Ethiopia SAM

Sector	Activity multiplier	Rank
Teff	3.27	6
Wheat	1.75	18
Maize	3.26	7
Cbarsor	3.29	5
Agricultural export crops	3.18	8
Censet	3.33	3
Cothrag	2.98	11
Livestock	**3.31**	**4**
Chome1	3.36	2
Chome2	3.37	1
Milling	2.80	13
Food products	2.35	17
Chemicals	0.91	20
Electricity	2.86	12
Water	3.01	10
Petroleum	0.74	22
Industrial manufacturing	1.55	19
Food manufacturing	0.90	21
Construction	2.77	14
Trade/transport	2.58	16
Government services	3.14	9
Other services	2.77	15

Source: Model simulations, based on unpublished Ethiopia SAM of Robinson 2009.

Table A3. Household multipliers from the Ethiopia SAM

Sector	Household multiplier	Rank
Teff	2.51	5
Wheat	1.28	18
Maize	2.53	3
Cbarsor	2.50	6
Agricultural export crops	2.45	8
Censet	2.53	4
Cothrag	2.18	11
Livestock	**2.65**	**1**
Chome1	2.63	2
Chome2	2.50	7
Milling	1.77	14
Food products	1.61	16
Chemicals	0.54	21
Electricity	2.00	12
Water	2.18	10
Petroleum	0.49	22
Industrial manufacturing	0.95	19
Food manufacturing	0.55	20
Construction	1.45	17
Trade/transport	1.70	15
Government services	2.18	9
Other services	1.95	13

Source: Model simulations, based on Ethiopia SAM of Robinson 2009.

Table A4. Household multipliers from the Ethiopia SAM

Sector	Household multipliers for rural poor		Factor income multipliers for livestock factors in pastoral and drought-prone areas	
	Multiplier	Rank	Multiplier	Rank
Teff	0.70	3	0.11	6
Wheat	0.34	18	0.05	18
Maize	0.66	6	0.11	5
Cbarsor	0.68	5	0.11	7
Agricultural export crops	0.58	9	0.11	8
Censet	0.64	7	0.11	4
Cothrag	0.56	10	0.09	9
Livestock	**0.84**	**1**	**0.42**	**1**
Chome1	0.72	2	0.16	3
Chome2	0.69	4	0.22	2
Milling	0.45	14	0.07	14
Food products	0.40	16	0.07	16
Chemicals	0.13	21	0.02	21
Electricity	0.49	12	0.08	13
Water	0.59	8	0.09	11
Petroleum	0.12	22	0.02	22
Industrial manufacturing	0.23	19	0.04	19
Food manufacturing	0.14	20	0.03	20
Construction	0.36	17	0.06	17
Trade/transport	0.42	15	0.07	15
Government services	0.52	11	0.09	10
Other services	0.49	13	0.09	12

Source: Model simulations, based on Ethiopia SAM of Robinson 2009.

Table A5. Household impacts from PARC rinderpest control program in Ethiopia

Household group	Income multiplier	Income gained under PARC (ECU)	Percentage of income received by group
Rural poor	0.84	12,034,441	32%
Rural non-poor	1.52	21,941,081	57%
Urban poor	0.05	785,084	2%
Urban non-poor	0.23	3,376,110	9%
TOTAL	**2.65**	**38,136,716**	**100%**

Source: Model simulations, based on Ethiopia SAM of Robinson 2009.

Table A6. Activity multipliers from the Kenya SAM

Sector	Activity multiplier	Rank
Maize	3.01	11
Wheat	0.14	50
Rice	1.37	45
Barley	3.16	3
Cotton	2.81	19
Other grains	3.03	10
Sugar	1.79	39
Coffee	3.09	8
Tea	3.08	9
Root crops	3.23	2
Oilseeds	3.10	6
Fruits	3.30	1
Vegetables	2.86	16
Cut Flowers	3.13	5
Other crops	3.00	13
Beef	**2.89**	**15**
Dairy	3.15	4
Poultry	2.90	14
Other livestock	2.68	22
Goats	2.84	17
Fish	2.32	33
Forestry	2.51	28
Mining	2.45	29
Meat processing	2.37	31
Milling	2.30	35
Bakery production	1.73	40
Beverages and tobacco	1.61	42
Other food manufacturing	0.78	46
Textiles	1.51	44
Footwear	2.01	38
Wood products	2.09	36
Printing	1.59	43
Petroleum	0.73	47
Chemicals	0.66	48
Machinery	0.57	49
Non-metallic products	2.06	37
Other manufacturing	1.62	41
Water	2.61	24
Electricity	2.41	30
Construction	2.35	32
Trading	2.75	20

Table A6. (Continued)

Sector	Activity multiplier	Rank
Hotel	2.71	21
Transport	2.32	34
Communication	2.81	18
Financial services	2.55	25
Real estate	2.51	26
Other services	2.66	23
Administration	2.51	27
Health	3.10	7
Education	3.00	12

Source: Model simulations, based on Kenya SAM of Kiringai et al. 2006.

Table A7. Household multipliers from the Kenya SAM

Sector	Household multiplier	Rank	Household multiplier (rural areas)	Rank
Maize	1.32	15	0.64	8
Wheat	0.07	50	0.04	50
Rice	0.53	43	0.23	41
Barley	1.62	1	0.91	1
Cotton	1.29	17	0.66	7
Other grains	1.49	5	0.79	2
Sugar	0.71	36	0.35	31
Coffee	1.24	19	0.60	11
Tea	1.49	4	0.75	4
Root crops	1.37	11	0.61	10
Oilseeds	1.44	7	0.72	5
Fruits	1.54	2	0.79	3
Vegetables	1.32	14	0.61	9
Cut Flowers	1.37	12	0.68	6
Other crops	1.26	18	0.57	15
Beef	**1.22**	**20**	**0.51**	**18**
Dairy	1.42	8	0.60	12
Poultry	1.40	9	0.59	13
Other livestock	1.34	13	0.54	16
Goats	1.39	10	0.58	14
Fish	0.96	28	0.35	30
Forestry	1.13	24	0.44	24
Mining	0.94	30	0.38	29
Meat processing	0.74	34	0.29	35
Milling	0.74	35	0.32	34
Bakery production	0.48	45	0.19	45
Beverages and tobacco	0.53	42	0.20	44
Other food manufacturing	0.26	46	0.10	46

Table A7. (Continued)

Sector	Household multiplier	Rank	Household multiplier (rural areas)	Rank
Textiles	0.56	41	0.23	42
Footwear	0.63	40	0.24	40
Wood products	0.67	38	0.25	39
Printing	0.51	44	0.20	43
Petroleum	0.21	48	0.08	48
Chemicals	0.22	47	0.09	47
Machinery	0.18	49	0.07	49
Non-metallic products	0.79	33	0.29	36
Other manufacturing	0.63	39	0.27	37
Water	1.30	16	0.50	20
Electricity	0.98	27	0.38	28
Construction	0.70	37	0.26	38
Trading	1.00	26	0.38	27
Hotel	0.95	29	0.39	25
Transport	0.85	32	0.34	33
Communication	1.17	22	0.45	22
Financial services	1.07	25	0.39	26
Real estate	1.21	21	0.47	21
Other services	1.16	23	0.44	23
Administration	0.93	31	0.35	32
Health	1.53	3	0.53	17
Education	1.44	6	0.50	19

Source: Model simulations, based on Kenya SAM of Kiringai et al. 2006.

Table A8. Household impacts from PARC rinderpest control program in Kenya

Household group	Income multiplier	Income gained under PARC (ECU)	Percentage of income received by group
Rural groups:			
Decile 0 (lowest)	0.01	42,275	1%
Decile 1	0.02	75,156	2%
Decile 2	0.03	106,583	3%
Decile 3	0.04	123,522	3%
Decile 4	0.04	150,932	4%
Decile 5	0.05	177,624	4%
Decile 6	0.06	196,345	5%
Decile 7	0.07	235,428	6%
Decile 8	0.08	274,888	7%
Decile 9	0.11	375,195	9%
Urban groups:			
Decile 0 (lowest)	0.00	19	0%
Decile 1	0.00	853	0%
Decile 2	0.00	2,664	0%
Decile 3	0.00	2,476	0%
Decile 4	0.00	10,977	0%
Decile 5	0.01	50,415	1%
Decile 6	0.04	136,723	3%
Decile 7	0.06	214,656	5%
Decile 8	0.12	420,491	10%
Decile 9	0.46	1,563,561	38%
TOTAL	**1.22**	**4,160,782**	**100%**

Source: Model simulations, based on Kenya SAM of Kiringai et al. 2006.

Table A9. Activity multipliers from the Pakistan SAM

Sector	Activity multiplier	Rank
Wheat	4.29	21
Paddy	4.55	15
Basmati paddy	4.42	18
Cotton	4.26	22
Sugarcane	4.67	13
Other crops	4.72	12
Horticulture	4.51	16
Cattle	**5.18**	**5**
Poultry	5.25	2
Forestry	3.94	23
Fish	4.90	8
Mining	0.86	33
Vegetable oils	3.85	26
Wheat flour	4.97	6
Rice	5.22	3
Basmati rice	5.18	4
Refined sugar	4.74	11
Other food	3.81	27
Yarn	4.37	20
Textiles	4.96	7
Leather	5.68	1
Wood	4.41	19
Chemicals	1.21	32
Ceramics	3.12	29
Petroleum	1.35	31
Manufacturing	1.37	30
Energy	3.59	28
Construction	3.93	24
Trading	4.84	10
Transport	3.90	25
Housing	4.89	9
Private services	4.58	14

Source: Model simulations, based on Pakistan SAM of Dorosh et al. 2003.

Table A10. Household multipliers from the Pakistan SAM

Sector	Household multiplier	Rank
Wheat	2.10	20
Paddy	2.35	13
Basmati paddy	2.25	16
Cotton	2.18	19
Sugarcane	2.41	9
Other crops	2.56	5
Horticulture	2.40	11
Cattle	**2.68**	**4**
Poultry	2.71	3
Forestry	2.24	17
Fish	2.55	6
Mining	0.47	33
Vegetable oils	1.63	28
Wheat flour	2.20	18
Rice	2.45	8
Basmati rice	2.40	10
Refined sugar	2.26	15
Other food	1.85	27
Yarn	1.88	24
Textiles	2.05	22
Leather	2.51	7
Wood	2.07	21
Chemicals	0.54	32
Ceramics	1.57	29
Petroleum	0.60	30
Manufacturing	0.60	31
Energy	1.86	25
Construction	1.86	26
Trading	2.76	1
Transport	1.95	23
Housing	2.74	2
Private services	2.33	14

Source: Model simulations, based on Pakistan SAM of Dorosh et al. 2003.

Table A11. Household impacts from a US$3 million increase in export demand for meat in Pakistan

Household group	Income multiplier	Income gained under increased exports	Percentage of income received by group
Large farm, Sindh	0.023	69,153	1%
Large farm, Punjab	0.071	213,029	3%
Large farm, Other Pakistan	0.015	44,303	1%
Medium farm, Sindh	0.057	170,855	2%
Medium farm, Punjab	0.134	403,355	5%
Medium farm, Other Pakistan	0.040	120,791	2%
Small farm, Sindh	0.085	255,040	3%
Small farm, Punjab	0.368	1,103,987	14%
Small farm, Other Pakistan	0.157	470,559	6%
Landless farmer, Sindh	0.067	199,899	2%
Landless farmer, Punjab	0.050	150,269	2%
Landless farmer, Other Pakistan	0.022	65,492	1%
Rural agricultural landless, Sindh	0.028	85,357	1%
Rural agricultural landless, Punjab	0.082	246,034	3%
Rural agricultural landless, Other Pakistan	0.018	52,769	1%
Rural nonfarm, nonpoor	0.261	784,181	10%
Rural nonfarm, poor	0.095	285,108	4%
Urban nonpoor	0.981	2,943,497	37%
Urban poor	0.125	373,550	5%
Total	**2.679**	**8,037,227**	**100%**

Source: Model simulations, based on Pakistan SAM of Dorosh et al. 2003.

Table A12. Activity multipliers from the Tanzania SAM

Sector	Activity multiplier	Rank
Maize	5.09	8
Paddy	4.96	16
Sorghum	5.12	7
Wheat	2.75	37
Beans	5.29	4
Cassava	4.97	15
Cereals	4.93	18
Oilseeds	5.23	5
Root crops	5.00	14
Cotton	4.93	17
Coffee	4.72	22
Tobacco	4.87	21
Tea	4.14	29
Cashews	5.07	11
Sisal	4.93	19

Table A12. (Continued)

Sector	Activity multiplier	Rank
Sugar	3.71	32
Other fruits and vegetables	5.08	9
Other crops	4.52	26
Livestock	**5.07**	**10**
Fisheries	5.04	12
Forestry	5.02	13
Mining	4.16	28
Meat processing	4.68	24
Grain processing	5.58	3
Processed food	3.88	31
Beverages	4.24	27
Clothing	3.70	33
Wood products	3.29	35
Chemicals	1.25	41
Fertilizer	2.45	38
Petroleum	0.64	43
Rubber, plastic, and other manufacturing	1.88	40
Glass and cement	3.60	34
Metal products	2.11	39
Manufacturing equipment	0.71	42
Utilities	4.65	25
Construction	4.70	23
Trade	4.90	20
Hotel	5.20	6
Transport	3.12	36
Real estate	6.93	1
Administration	5.82	2
Private services	4.01	30

Source: Model simulations, based on Tanzania SAM of Thurlow and Wobst et al. 2003.

Table A13. Household multipliers from the Tanzania SAM

Sector	Household multiplier	Rank	Household multiplier (rural areas)	Rank
Maize	3.17	4	2.41	4
Paddy	2.93	13	2.18	13
Sorghum	3.09	11	2.34	11
Wheat	1.60	37	1.16	36
Beans	3.27	1	2.46	1
Cassava	3.16	6	2.43	3
Cereals	2.95	12	2.19	12
Oilseeds	3.27	2	2.44	2
Root crops	3.16	5	2.40	6

Table A13. (Continued)

Sector	Household multiplier	Rank	Household multiplier (rural areas)	Rank
Cotton	2.72	20	1.94	20
Coffee	2.76	18	2.02	18
Tobacco	2.72	21	1.96	19
Tea	2.31	28	1.67	25
Cashews	3.15	9	2.35	9
Sisal	2.62	23	1.90	22
Sugar	2.23	30	1.67	27
Other fruits and vegetables	3.21	3	2.40	5
Other crops	2.82	17	2.14	14
Livestock	**3.13**	**10**	**2.34**	**10**
Fisheries	3.16	7	2.37	8
Forestry	3.15	8	2.39	7
Mining	2.52	26	1.67	26
Meat processing	2.70	22	2.03	17
Grain processing	2.84	16	2.10	16
Processed food	2.06	32	1.47	31
Beverages	2.24	29	1.55	30
Clothing	2.04	33	1.38	33
Wood products	1.80	35	1.23	34
Chemicals	0.59	41	0.40	41
Fertilizer	1.28	38	0.86	38
Petroleum	0.36	43	0.24	43
Rubber, plastic, and other manufacturing	0.94	40	0.63	40
Glass and cement	1.84	34	1.22	35
Metal products	1.02	39	0.68	39
Manufacturing equipment	0.36	42	0.24	42
Utilities	2.57	25	1.71	24
Construction	2.45	27	1.65	28
Trade	2.86	15	1.90	21
Hotel	2.72	19	1.87	23
Transport	1.72	36	1.14	37
Real estate	2.92	14	2.13	15
Administration	2.62	24	1.65	29
Private services	2.16	31	1.44	32

Source: Model simulations, based on Tanzania SAM of Thurlow and Wobst et al. 2003.

Table A14. Household impacts from PARC rinderpest control program in Tanzania

Household group	Income multiplier	Income gained under PARC (ECU)	Percentage of income received by group
Rural, below food poverty line	0.22	794,539	7%
Rural, between food and basic needs poverty lines	0.30	1,089,979	9%
Rural non-poor—head with no education	0.41	1,500,417	13%
Rural non-poor—head not finished primary school	0.43	1,585,840	14%
Rural non-poorhead not finished secondary school	0.89	3,257,344	28%
Rural non-poor—head finished secondary school	0.10	363,209	3%
Urban, below food poverty line	0.03	124,901	1%
Urban, between food and basic needs poverty lines	0.06	225,129	2%
Urban non-poor—head with no education	0.06	216,868	2%
Urban non-poor—head not finished primary school	0.09	346,657	3%
Urban non-poor—head not finished secondary school	0.39	1,446,587	13%
Urban non-poor—head finished secondary school	0.15	541,884	5%
Total	**3.13**	**11,493,353**	**100%**

Source: Model simulations, based on Tanzania SAM of Thurlow and Wobst et al. 2003.

Table A15. Activity multipliers from the Uganda SAM

Sector	Activity multiplier	Rank
Coffee	3.63	11
Cash crops	3.49	14
Maize	3.85	7
Sorghum/millet	3.87	3
Cassava	3.86	5
Sweet potato	3.86	4
Matoke	3.88	2
Horticulture	3.85	6
Other agriculture	3.65	10
Livestock	**3.84**	**8**
Forestry	3.73	9
Fishing	3.62	12
Meat and dairy processing	2.91	21
Coffee processing	4.32	1
Grain milling	3.22	17
Other beverages	3.36	16
Textiles and leather	1.45	23
Manufacturing	1.22	24
Fertilizers	0.65	26
Petroleum and chemicals	0.94	25
Utilities	3.03	20
Construction	3.09	19
Commerce	3.51	13
Transport	2.45	22
Private services	3.17	18
Public services	3.45	15

Source: Model simulations, based on Uganda SAM of Dorosh and El-Said 2004.

Table A16 Household multipliers from the Uganda SAM

Sector	Household multiplier	Rank	Household multiplier (rural areas)	Rank
Coffee	2.65	11	2.20	9
Cash crops	2.44	14	1.96	13
Maize	2.97	6	2.44	7
Sorghum/millet	3.00	3	2.46	3
Cassava	2.99	4	2.45	4
Sweet potato	3.00	2	2.47	2
Matoke	3.01	1	2.48	1
Horticulture	2.98	5	2.45	5
Other agriculture	2.84	8	2.33	8
Livestock	**2.96**	**7**	**2.44**	**6**
Forestry	2.69	10	2.19	11
Fishing	2.69	9	2.19	10
Meat and dairy processing	1.89	21	1.47	18
Coffee processing	2.55	12	2.05	12
Grain milling	2.08	19	1.60	17
Other beverages	2.17	18	1.65	15
Textiles and leather	0.94	23	0.70	23
Manufacturing	0.79	24	0.52	24
Fertilizers	0.47	26	0.34	26
Petroleum and chemicals	0.61	25	0.43	25
Utilities	2.24	16	1.26	21
Construction	1.95	20	1.41	19
Commerce	2.52	13	1.84	14
Transport	1.48	22	1.07	22
Private services	2.29	15	1.61	16
Public services	2.18	17	1.41	20

Source: Model simulations, based on Uganda SAM of Dorosh and El-Said 2004.

Table A17. Household impacts from PARC rinderpest control program in Uganda

Household group	Income multiplier	Income gained under PARC (ECU)	Percentage of income received by group
Urban poor	0.05	248,655	2%
Urban non-poor	0.47	2,564,737	16%
Rural farm zone 1	0.49	2,623,632	16%
Rural farm zone 2	0.51	2,775,464	17%
Rural farm zone 3	0.28	1,520,870	9%
Rural farm zone 4	0.19	1,029,394	6%
Rural farm zone 5	0.09	462,424	3%
Rural farm zone 6	0.34	1,853,467	12%
Rural nonfarm	0.54	2,942,653	18%
Total	**2.96**	**16,021,296**	100%

Source: Model simulations, based on Uganda SAM of Dorosh and El-Said 2004.

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