

Smallpox Eradication in West and Central Africa: Surveillance-Containment or Herd Immunity?

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The global eradication of smallpox stands among the most important public health achievements of the last century.¹ However, fears that smallpox bioweapons^{2,3,4} have fallen into the hands of rogue states or terrorist organizations have rekindled interest in the methods used to control smallpox outbreaks. Surveillance-containment employing ring vaccination, whereby symptomatic smallpox cases were sought and isolated and their surrounding contacts traced and vaccinated, has been widely acknowledged as the key to smallpox eradication,¹ though some have questioned this claim⁵. In the United States, where the interim policy in the event of a smallpox attack is based on ring vaccination,⁶ we have argued that localized mass vaccination from the moment an attack is recognized would result in far fewer casualties than ring vaccination, including deaths that result from vaccination itself.⁷ In this commentary, we closely examine a figure based on historical data reported by Foege *et al*^{8,9} documenting smallpox control and eradication in West and Central Africa. This figure has been resurrected as empirical proof of the effectiveness of ring vaccination, and presented in important meetings addressing smallpox response policy in the United States¹⁰. It is important that data offered to garner support for a policy position stand on their own as presented, and indeed it was the public presentation of this figure that prompted our investigation. Contrary to

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the claim made, we will argue that the reported decline in smallpox cases matches what one would have expected on the basis of increased vaccination coverage alone. Herd immunity, not surveillance-containment, appears to be the real story behind the eradication of smallpox in West and Central Africa.

The key result of Foege *et al* presented in support of ring vaccination was reproduced from Figure 9 of their paper in the *Bulletin of the World Health Organization* (see *Ref. 8*; this same figure first appeared as Figure 2 in *Ref. 9*). We have reproduced this figure as shown publicly as Figure 1¹⁰. This figure reports the ratio of reported to “expected” cases of smallpox both before and after the initiation of surveillance-containment in West and Central Africa, as well as the percentage of the population that was not vaccinated. Though these data were aggregated over age and over twenty different countries, the intent of the figure is clear: note the seemingly sudden decline in the ratio of reported to expected cases after the surveillance-containment activities began. Indeed, with reference to this figure, Foege *et al* report that “The results were dramatic” (p. 218 in *Ref. 8*).

However, closer examination raises several questions about the decline observed. First, note the logarithmic scale on the vertical axis. To the untrained eye, the drop from 100% to 10% appears equivalent to the drop from 10% to 1%. The clear impression is that while the percentage of the population that was not vaccinated declined slowly over time, the ratio of reported to expected smallpox cases fell like a rock shortly after surveillance-containment began. In fact, vaccination coverage *tripled* – from 20% to

60% -- between January 1968 and March 1969. This change in vaccination coverage is visually eclipsed by the February through March 1969 drop in the reported-to-expected smallpox case ratio, yet the latter decline was only nine percentage points. Why was a logarithmic scale employed to report these data?

Second, expected smallpox cases were computed without accounting for the tripling in vaccination coverage just noted. Rather, the authors considered the average number of cases reported monthly from 1960-67 (reported as Figure 3 in *Ref. 8* and reproduced as Figure 2 below) as an indication of the number of smallpox cases that should be expected. Note in particular the increasing trend in monthly reported cases from January through April. That January through March are the last three months included in computing the ratio of reported to expected cases further exacerbates the illusion that smallpox cases declined much more than expected. There are generally two things that can go wrong when computing a ratio: the numerator and the denominator. In the present application, the denominator is simply a historical average of past cases, ignoring the important tripling in vaccination coverage that actually occurred.

Taken together, Figures 1 and 2 (Figs. 9 and 3 in *Ref. 8*) enable one to determine the actual number of smallpox cases reported in West and Central Africa over the time period of interest. The actual reported cases, along with the percentage of the population that was not vaccinated as deduced from Figure 1, appear in Figure 3. Here there is no mystery. More or less in lockstep over time, both the fraction of the population that was unvaccinated and the reported number of smallpox cases declined.

A different view of these same data is shown in Figure 4, where for each month we have plotted the reported number of smallpox cases against the fraction of the population that was vaccinated. The implication is very clear: as vaccination coverage tripled from 20% through 60%, monthly smallpox cases in West and Central Africa declined from approximately 800 to 30.

In contrast to Figure 1, it is no longer possible to identify September 1968 (or thereabouts) as the initiation date of surveillance-containment from Figures 3 and 4. Worded differently, once the increase in vaccination coverage is taken into account, there is little left to explain in the reported pattern of smallpox cases over time. The relationship between vaccination coverage and the number of reported cases is the same before and after September 1968. One could argue that the surveillance-containment activities were required to obtain the tripling in vaccination coverage achieved, but the clear conclusion remains the same: it was the tripling of vaccination coverage that contributed most to the eradication of smallpox in this part of the world.

That the decline in smallpox cases can be explained plausibly by increased vaccination coverage as opposed to surveillance-containment is an important lesson to understand as smallpox control methods are revisited in the current bioterror policy debate. Before surveillance-containment activities began in September 1968, 45% of the population had been vaccinated, while survivorship from past smallpox outbreaks implied even higher levels of immunity. By contrast, in the United States and many other

countries today, there is virtually no immunity to smallpox. While we have argued previously that ring vaccination would work better in areas with higher rather than lower levels of population immunity,⁷ the analysis reported herein casts serious doubts on the value-added by surveillance-containment over mass vaccination even in areas where nearly half of the population had been vaccinated. These results strengthen our conviction that in the event of a smallpox bioterror attack, rapid mass vaccination in the area of the attack with the goal of reaching herd immunity as quickly as possible should be preferred in favor of a ring vaccination strategy. Moreover, because bioterror-induced smallpox outbreaks would likely lead to cases worldwide, planning should begin now to ensure that rapid vaccination could be implemented immediately in inflicted regions around the globe. It is therefore important that policymakers in developed countries and at the World Health Organization formulate a strategy for coping with global outbreaks when devising their vaccine stockpiling and distribution policies.

References

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² Alibek K. *Biohazard*. New York: Random House, 1999.

³ Miller J, Engelberg S, Broad W. *Germs*. New York: Simon and Schuster, 2001.

⁴ Tucker JB. *Scourge: The Once and Future Threat of Smallpox*. New York: Atlantic Monthly Press, 2001.

⁵ Anderson RM, May RM. *Infectious Diseases of Humans: Dynamics and Control*. Oxford: Oxford University Press, 1991 (see especially p. 90).

⁶ Centers for Disease Control and Prevention. *Interim Smallpox Response Plan and Guidelines*. Atlanta: Centers for Disease Control, 2002 (retrieved on October 13, 2002 from <http://www.bt.cdc.gov/agent/smallpox/response-plan/index.asp>; see especially p. 4 of the Executive Summary, retrieved from <http://www.bt.cdc.gov/agent/smallpox/response-plan/files/sections-i-iv.pdf> on the same date, which states that “Any vaccination strategy for containing a smallpox outbreak should use the ring vaccination concept.”).

⁷ Kaplan EH, Craft DL, Wein LM. Emergency response to a smallpox attack: The case for mass vaccination. *Proc Natl Acad Sci USA* 2002; **99**: 10395-40.

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⁹ Foege WH, Millar JD, Lane JM. Selective epidemiologic control in smallpox eradication. *Am J Epidemiol* 1971; **94**: 311-315.

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Figures

Figure 1: The effect of surveillance-containment on the ratio of reported to expected smallpox cases in West and Central Africa (reproduced from Figure 9 in Foege *et al*⁸). Note the logarithmic scale on the vertical axis, and the definition of expected cases as the 1960-67 monthly average.

Figure 2: Monthly “expected” smallpox cases, that is, the 1960-67 monthly average number of reported cases (reproduced from Figure 3 in Foege *et al*⁸). Note the upturn in expected monthly cases from January through April, and the impact of this on the ratio of reported to expected smallpox cases plotted in Figure 1.

Figure 3: Actual reported smallpox cases and the percentage of the population unvaccinated in West and Central Africa from January 1968 through March 1969. Data from Foege *et al*⁸.

Figure 4: Actual reported smallpox cases as a function of vaccination coverage in West and Central Africa. Data from Foege *et al*⁸.

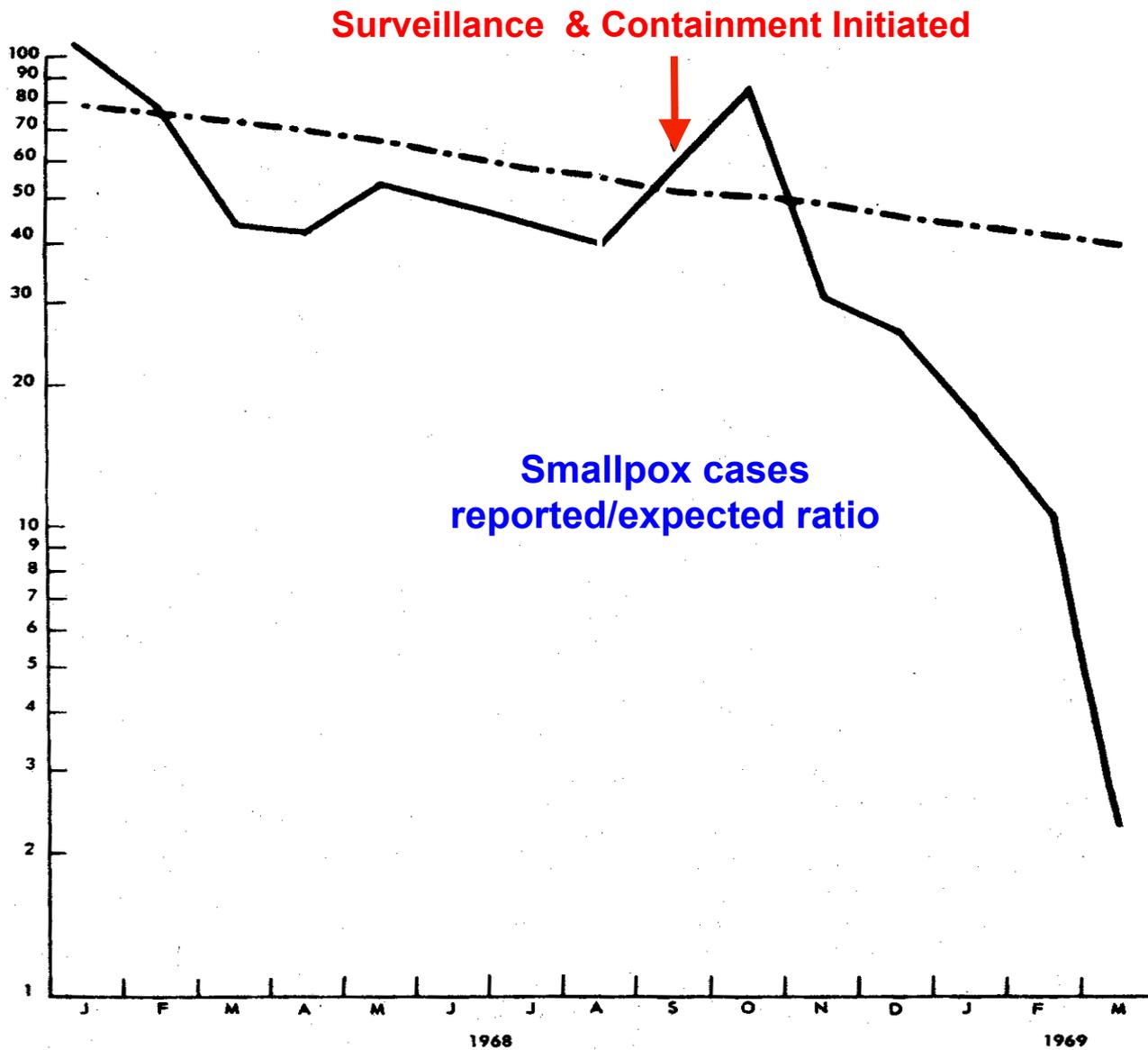
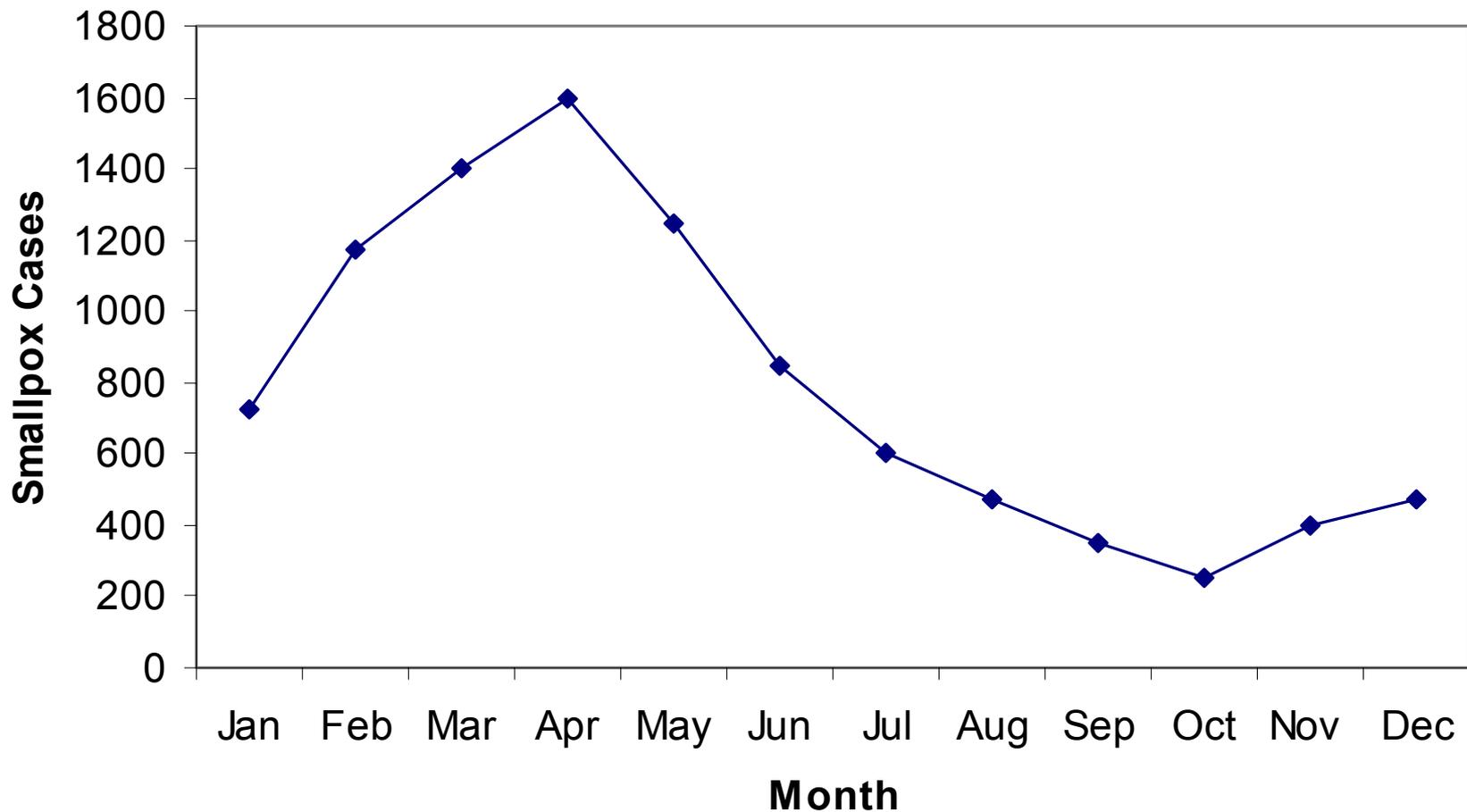
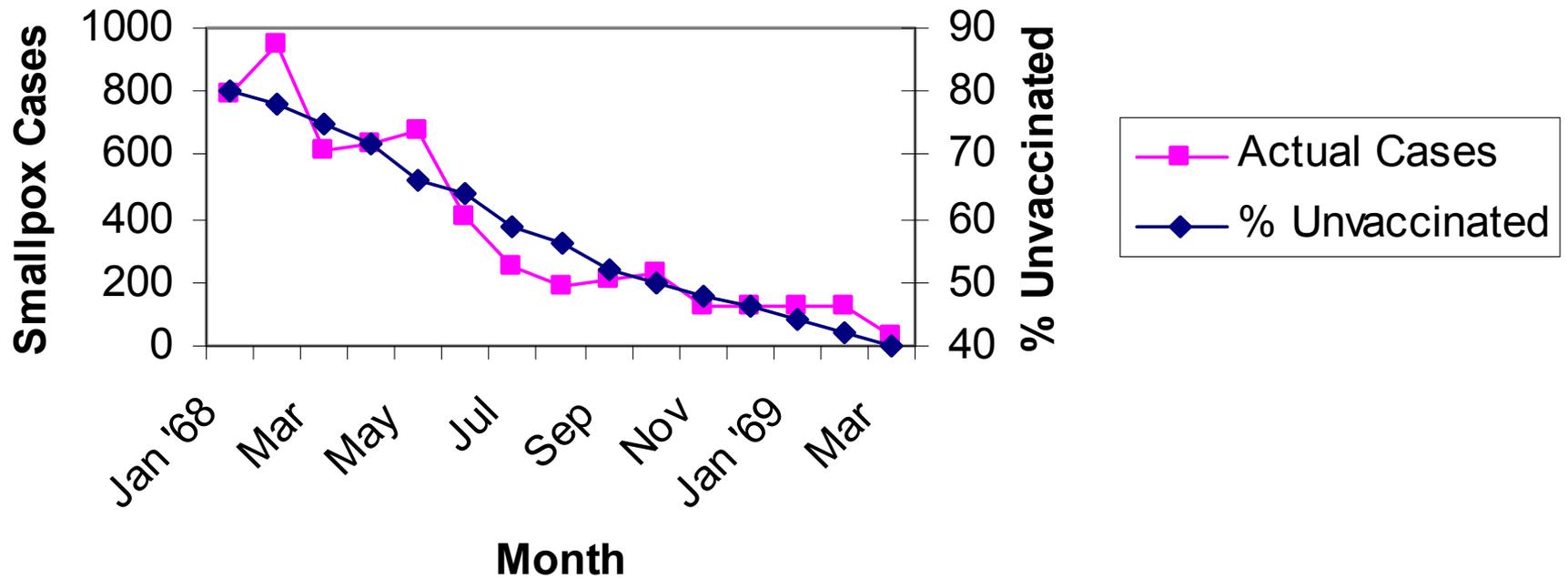


Fig. 9. The percentage of the population not vaccinated in the smallpox eradication programme area (broken line) compared with the ratio (%) of reported smallpox cases to cases expected from the 1960–67 monthly average (solid line). The arrow marks the start of surveillance–containment activities.

Mean Monthly Smallpox Cases As Reported in Foege *et al*, 1975



Reported Cases and % Unvaccinated (Foege *et al*, 1975)



Smallpox Cases Accounting for % Vaccinated (data from Foege *et al*, 1975)

