Discovering Epidemiology and One Health

For scientists joining the new health collaboration

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Abstract

In late 2025 I was welcomed to the field of epidemiology by colleagues in rule-based modelling. I soon noticed that on the one hand, amazing techniques save lives at scale, but on the other, emerging diseases and newer health-related epidemics are accelerating. I needed to learn:

- What is epidemiology?
- Can it stop new epidemics?
- Is it about health, or diseases?
- How can a scientist quickly grasp epidemiology basics?

Beginning with what epidemiology *is not*, we see how disease management saved millions of lives from about 1950. Epidemiology matured through the 20th century but stalled in the early 21st. It became clear that epidemiology was insufficient, so political consensus was found to expanded the scientific scope to **One Health**. One Health treats ecology, animals and humans as a system of systems across dozens of science fields, using the language of epidemiology. The newly-refocused World Health Organisation is committed to get 2030 global health goals back on track with a One Health approach, with further millions of lives at stake.

Many new One Health scientists are not epidemiologists, and this paper is for them.

Contents

1 Introduction

We could learn what epidemiology *is* from many freely available texts[1], but these are not aimed at the computer scientists, ecologists, veterinarians, climate scientists etc contributing to One Health.

We could also study the origins and history of epidemiology, but this too seems unnecessary for prospective One Health scientists.

Instead, I suggest the following method.

For a sufficient working knowledge of epidemiology:

1. learn definitions from Appendix A: *Cheatsheet glossary for non-epidemiologists*.
2. study the section What is epidemiology *not just?*, especially the diagram. This situates epidemiology within history, technology and statistics.
3. study the section What exactly is One Health? In the West at least, many epidemiologists are still getting used to this.
4. read any one of the references in Appendix E: *US withdrawal from WHO and One Health*, because this is the biggest challenge to One Health today.

The biggest picture is that at each major step towards modern epidemiology, millions of deaths were prevented. Epidemiology saves life, and improves life at scale, in a measurable way.

2 What is epidemiology *not just?*

We start with what epidemiology *is not just*.

Epidemiology:

- *is not just* the practice of medicine. If that were true, then epidemiology would begin with the skilled healthcare of quarter of a million years ago.
- *is not just* rational, documented medicine. If that were true, then epidemiology would begin 2400 years ago with meticulous clinical case notes which seek to identify natural (not divine) causes.
- *is not just* effective public health. If that were true, then epidemiology would

[1] In English alone, excellent texts include [World Health Organization(WHO) and Bonita, Ruth and Beaglehole, Robert and Kjellstrom, Tord 2012][Bovbjerg 2021][Baker 2020, chap. 1.1] [Illinois 2020][Disease Control and Prevention 2006][OpenStax 2021].

begin with the government systems of hospitals, vaccinations, written records and social care of 1000 years ago.

- *is not just* modern scientific medicine. If that were true, then epidemiology would begin with the era of germ theory, sanitation and rapid development of medical science from 150 years ago.

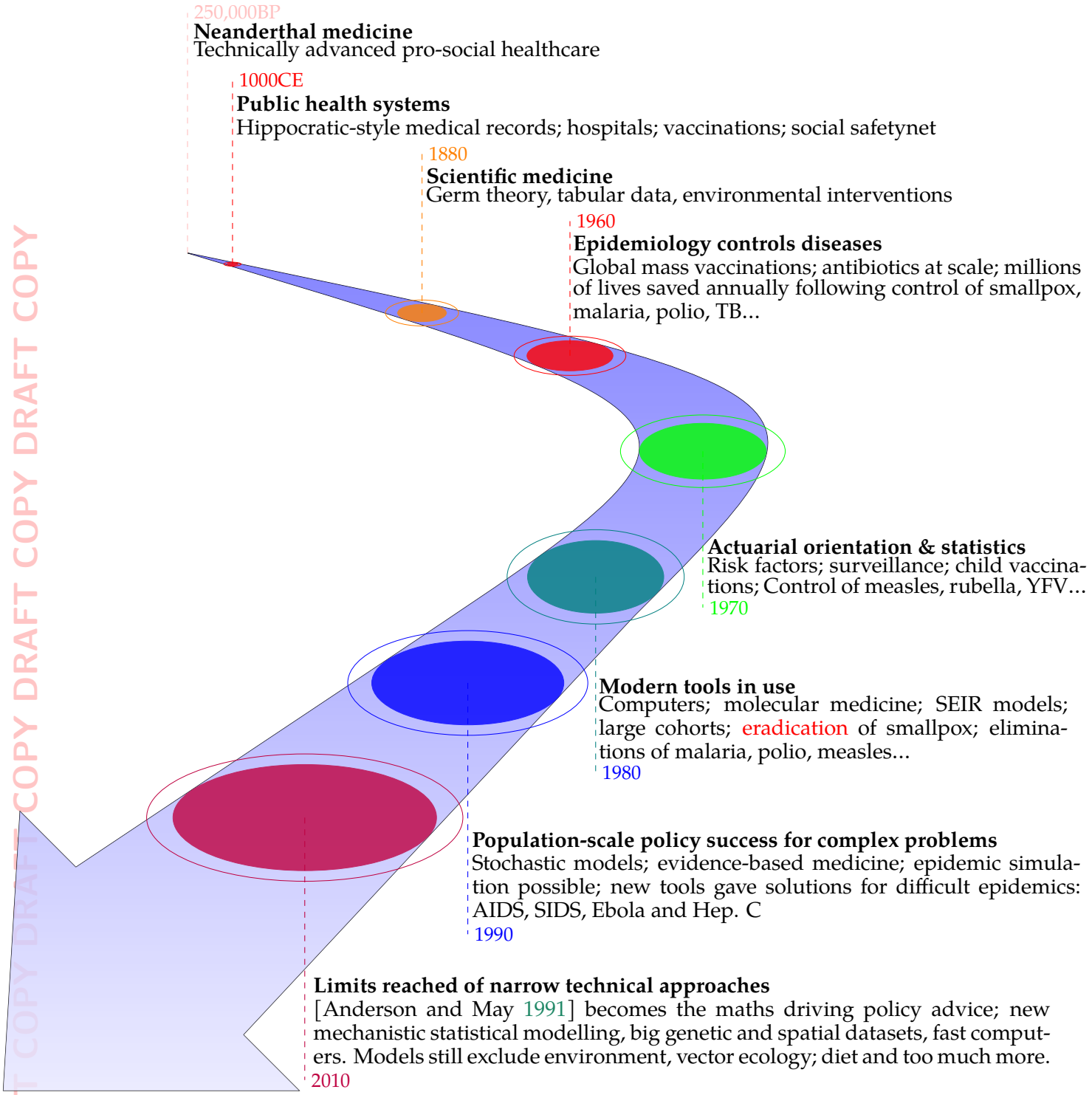
These are essential, life-saving steps towards epidemiology, but not effective disease management. Consider that despite medical progress 1900-1950, at least *600 million people* died from smallpox, TB, malaria and the 1918 flu alone, and at least *15% of children* died before their first birthday[McKeown 1976][Deaton 2013]. And that was the century of antibiotics, improved nutrition, sanitation and institutional structures – the toll in previous centuries was far higher.

Then, 75 years ago, entire populations of urbanised people (even some poor and colonised ones) were made safe from deadly pathogens and behaviours. From about 1950 epidemiologists had standard scientific ways to reason about health and perform mathematical calculations. Whole societies engaged with mass efforts to implement policy arising from this reasoning.[2] Diseases were controlled and then suppressed, en route to elimination.

Epidemiology really took off from 1950 and until about 2010 the field had clear but frequently-changing boundaries. This was the epidemiology I incorrectly thought I had joined – take some medical data, perform calculations, produce graphs, analyse policy options, and provide advice to save lives. But no, epidemiology is now part of something much larger.

The following diagram illustrates the epidemiology progression. The dates given in the diagram are when the knowledge described is applied in widespread use, not its invention or first known use.

[2] The kind of reasoning our RBEM group puts to policymakers, which is very exciting.



One Health 2010-2026

Since about 2010, for the first time in history, technical ability and political motivation emerged to bring together dozens of scientific and medical fields. Their combined knowledge is used to calculate health results across humans, animals and ecology, in the acceleration project to get the derailed world health development goals back on track. The Global One Health Index[Zhang et al. 2024] tracks progress.

The US reneged in 2025, destroying surveillance programmes, exiting hundreds of multilateral health agreements, and targeting One Health for defunding.

The world is reponding, committing again and again to One Health. But the funding fight to save lives is ongoing.

This is the new epidemiology in 2026.

The last node in the timeline highlights advanced epidemiology, observing that progress slowed and therefore lives were being lost. During the whole of the 20th century Western societies seemed to abandon the idea of human health depending on the environment, until faced with intractable new diseases when this was embraced again. More detail is in Appendix C: *How did Epidemiology forget the environment?*.

3 What exactly is One Health?

One Health holds that population health is impacted by the environment, social activities, climate and animal health, besides the expected pathogens and medical conditions. Most of the natural and social sciences have a place in One Health, and more besides[Meisner et al. 2024].

Now we need to look at how epidemiology's familiar 20th century silo-style approach is an historical anomaly. Many within One Health are feeling their way through the transition to break down these silos, which is more like a reversion to the mean than a new approach. As will be shown, it is very relevant that collaboration with non-human aspects has been a normal way to improve health.

Two well-documented historical examples date from about 2300 years ago: the famous doctor Hippocrates in Kos (near modern-day Turkey), and Ashoka, king of a vast empire centred on modern-day India. Hippocrates wrote about the environment in his medical case notes (see Appendix B: *Historical steps towards epidemiology*) and King Ashoka issued edicts on the topic including the following:

Ashoka Rock Edict XIV, 257BCE

Everywhere, I, Ashoka, King Priyadarsi, Beloved of the Gods, have arranged for two kinds of medical treatment: medical treatment for men and medical treatment for animals. [Woolner 1924]pp. 5-6

Scientific One Health is often traced to Al-Razi of Bagdhad[Tibi 2006], with the Royal College of Physicians of Edinburgh highlighting his meningitis trial[Tibi 2005] published in 900CE. Al-Razi's Comprehensive Book of Medicine[3] contains notes of his environmental engineering and animal care to prevent zoonoses and vector borne diseases.

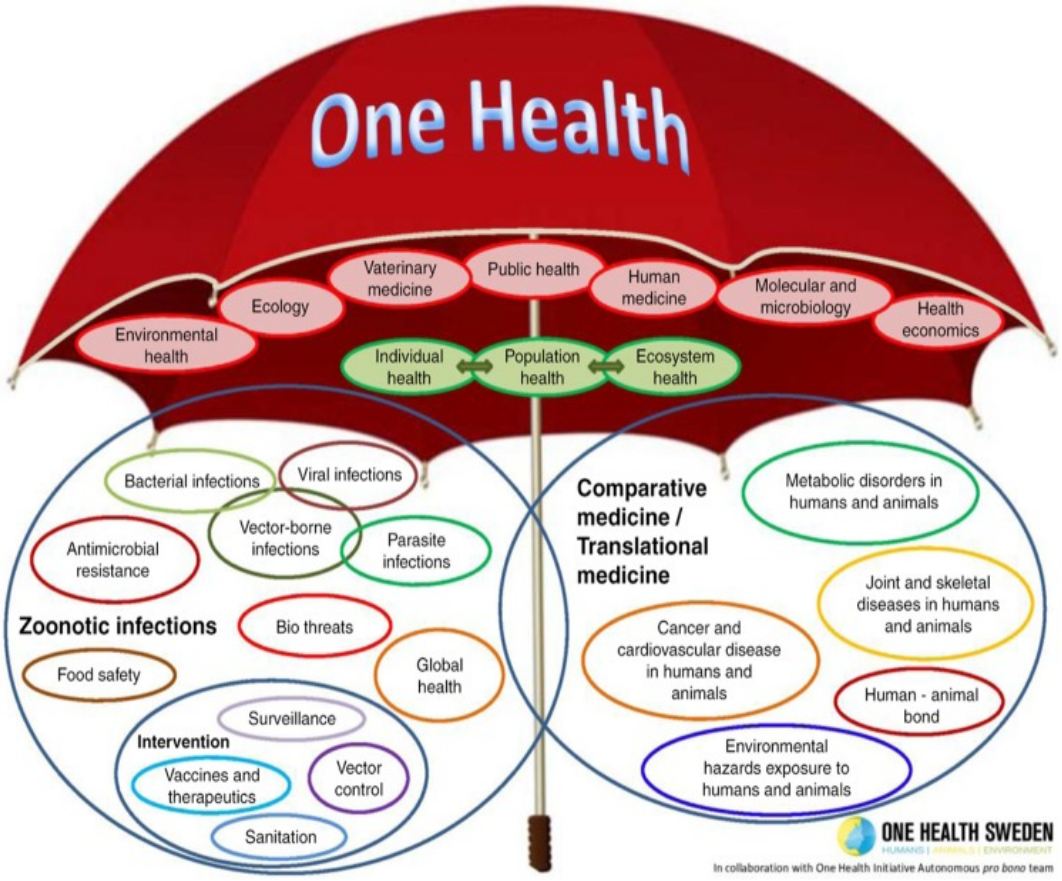
In modern times [Schwabe 1984] published on human and animal health, often re-

[3] this Arabic book[al-Rāzī 1955–1971] has many thousands of pages. The Latin translation is *Liber Continens* ("Book of Everything") a collection of al-Rāzī's notebooks, clinical observations, and excerpts from foreign medical texts – all the medical knowledge he could find. Liber Continens was a European bestseller for centuries, the most expensive book of its time and still the only complete translation.

garded as establishing the One Health concept.

Like the convergence of 75 years ago when epidemiology took effect, around 2010 a critical mass of technical methods, political will and inter-disciplinary cooperation emerged. One Health took effect, and now in 2026 there are hundreds of thousands of references to One Health in the literature, with more every week.

A helpful but overly biomedical illustration[Lerner and Berg 2015] is:



Many non-biomedical disciplines should also be under this umbrella.

In any case, One Health is the approach most of the governments and supporting organisations in the world have chosen to address to our whole-ecosystem health problems.

To answer the question **what is One Health?** I first went to a bland official definition: *One Health is an unifying approach to sustainably balance and optimise the health of humans, animals, and ecosystems through coordinated action across multiple sectors, disciplines, and levels of society* [Food and Agriculture Organization of the United Nations et al. 2025]. I found WHO's informative One Health fact sheet and the Berlin Principles of One Health[Gruetzmacher et al. 2021] are key.

None of these really help scientists just wanting to be informed. Dissatisfied, I looked

at what is unique about One Health, starting with its scope.

What distinguishes One Health from other large-scale scientific initiatives is operational complexity: it demands integration not only of diverse scientific disciplines but also of different knowledge systems (traditional and scientific), different operational timescales (immediate clinical response alongside long-term ecological monitoring), and vastly different professional cultures, all while maintaining real-time surveillance and response capabilities. At a technical level [Oltean et al. 2025] identifies challenges to "radical multidisciplinarity" merely within the United States including recording individual health in a compatible way with measurements about rivers. Politically, [Lee and Brumme 2023] discusses scope and scale, including who is paying for One Health and who is making the rules. I conclude that while One Health shares common features with the IPCC, national combined science organisations and large space programmes, it exceeds them all in complexity and vastness.

I identified some defining characteristics of One Health:

- Singular focus on improving collective health of humans, animals and ecosystems.
- Urgent, due to emerging diseases, vulnerable populations, and accelerating anthropogenic behaviour.
- Slow, due to so many organisations needing to work together for the first time.
- Systemic, needing to study and make changes in systems of systems of systems.
- Highly political, due to impacts on national wellbeing, wealth, prestige and competitiveness and the power imbalance disfavouring the global South.
- Deciding things hitherto unknown: what should we be counting? What are the official numbers of these things?
- Especially harmed by US actions: many, arguably most, of the hundreds of the targeted multilateral treaties, organisations and science collaborations have to do with One Health.

In many ways the global discussion has only just started. Multi-disciplinary questions are being addressed at the regional and country grouping level though, including things such as:

- What standards can we agree on for measuring the deluge of data from -omics and real-time observations?
- Who is going to fund surveillance and ongoing measures which are less visible than emergency response?
- Which sentinel species should we surveille for chemical pollution, cancer and obesity?

- Which changes in farming practices can stop specific vectors increasing their range?
- What preventative measures should we deployed right now against zoonotic spillover of prion diseases?
- Should we prioritise AMR reservoirs in ecosystems over humans?
- What plant species best reverse urban deforestation to slow emerging diseases?

There seems a great deal of One Health activity in regions with uneven development, indicated by progress papers in e.g. China[Gao et al. 2025],[Wei et al. 2025], South America[Manterola et al. 2024] and others. Developed countries including in Europe are highly vulnerable but seem a little slower to adapt to the new epidemiology.

And now, to work!

Suggestions for starting in One Health:

- Search Google Scholar to see what is already happening in your field: *"One Health" sociology* or *"One Health" criminology* or *"One Health" astrobiology* etc.
- Make a list of variables you measure that are relevant to One Health. Your knowledge of relevance is specific to your discipline and therefore essential to other scientists.
- Make a list of rates that you know, or could design an experiment to know. With variables and rates curated by a specialist, an epidemiological modeller can make rapid progress.
- Start talking about One Health. While there is brisk activity in nearly every field, most scientists are not yet engaged because this is so young. Ask your colleagues.
- Find out the position of your government and your organisations for health and ecology: who within them are advertising their One Health approach?

4 Conclusion

Epidemiology has embraced a wide range of sciences because today's health threats are more complex and amplified by anthropogenic activity. By addressing the health needs of entire ecosystems the hope is that ill-health in the broadest sense can be addressed, because it is now clear that unless the plants and animals are healthy the humans won't be either. The resulting scientific collaboration is still recognisable as epidemiology because that is where its measurables and methods come from, and therefore also its language of communication: rates of health and disease; expected impact of society-wide interventions, and causal information.

The 2025 World Health Statistics Report [WHO 2025] is clear health progress has been derailed. In response, the current WHO work programme aims to dramatically accelerate health progress by the end of 2026 and global commitments to One Health have increased despite the instability caused by US actions as discussed in Appendix E: *US withdrawal from WHO and One Health*.

One Health is hugely ambitious, involves most of the natural and social sciences, and has made very uneven progress. Nevertheless if the 2030 WHO report is happier reading then that will be due to epidemiology's new clothes: One Health.

Appendices

Appendix A Cheatsheet glossary for non-epidemiologists

This cheatsheet explains a minimum subset of the language of epidemiology for scientists in a hurry. Better glossaries are available[4]

Health related states or events This is a clumsy term, but it means "everything epidemiology studies". That covers infectious diseases such as measles, non-infectious diseases such as diabetes, violence [Ransford et al. 2025] and even online misinformation[Gavric et al. 2025]. Epidemiologists are not just disease detectives, although they certainly are that.

Anthropogenic Caused by human activity, typically used in a negative sense such as pollution, climate change and ecocide. If it wasn't for anthropogenic pressures maybe we wouldn't need One Health.

Pathogen A virus, bacteria, parasite or fungus that that causes disease in a host human, animal or plant. The pathogen infects the host, and is a microorganism.

Reservoir This is any place or thing where a pathogen can survive ready to infect. Examples include: rabies and ebola persist in bat populations; legionella bacteria live in water systems; malaria parasites and measles viruses live in human hosts. When conditions are right the pathogen exists in numbers ready for an epidemic. This is why eradicating a disease is so difficult.

Vector a living organism that transmits pathogens from an infected host or the environment to a host. Examples are ticks, mosquitoes, fleas, flies and rats. The vectors may feed on blood, or leave infected faeces for humans to touch. Warmer climates increase vector activity and therefore disease risk. If there were no reservoirs there would be nothing for the vectors to transmit.

Natural history The progression of a disease process in an individual over time, as understood by medical and biological science. For example the natural history of measles includes its various stages (incubation, fever period, rash stage, and recovery); its complications (swelling of the brain, pneumonia, death etc); transmission characteristics; and prognoses.

Control Reducing disease to an acceptable level in one geographic area, perhaps by a vaccination campaign or reducing breeding places for particular insects. The disease will continue to circulate.

Suppression Reducing the number of cases to very low levels, often through multiple aggressive interventions. "Aggressive" here means "very keen, well-funded or even mandatory". Examples are mass testing and COVID-19 lockdowns. The disease will continue to exist and may bounce back once measures are stopped.

[4] from e.g. the US CDC[Disease Control and Prevention 2024], WHO[WHO 2004], John Hopkins School of Public Healh[Public Health 2018] and even an EU food safety One Health glossary.

Elimination Reducing disease in a particular geographic area, usually a country or region. This requires ongoing surveillance (that is, constant testing but not mandatory testing) and usually mass vaccinations, and often high levels of hospital care during the elimination. The disease will still exist, and needs to be addressed whenever surveillance shows an outbreak is occurring.

Eradication Totally erasing the disease from the world, except in laboratory jars. This is very difficult and rare, and has only happened in the case of one and almost two diseases ever: Smallpox, and almost Dracunculiasis (sometimes Guinea-worm). In the theme of One Health, we could add the disease Rinderpest, a cattle disease that has been eradicated and therefore cannot mutate and harm other species including humans.

-demic words An *endemic* disease is constantly present in a particular population, like baseline seasonal flu in winter in temperate countries. An *epidemic* is a sudden, large increase in a disease beyond what is expected, confined to a particular geographic region. A *pandemic* is an epidemic in many regions or multiple continents, potentially global. The Greek dēmos means "people", so none of these apply to non-human animals.

Zoo-words A *zoonosis* is a disease can spread from non-human animals to humans, for example rabies from a dog bite. There are hundreds of *zoonoses*, comprising a majority of infectious diseases in humans. *Zoonotic spillover* is the first occasion when all the factors align and a disease has changed enough to jump from animals to humans. *Zoodemic* is expected disease, equivalent to endemic in humans. Non-human animals have *epizootic* and *panzootic* events, corresponding to epidemics and pandemics. Unsurprisingly, zôon means "animal" in Greek.

Rates Epidemiology requires counting things over time, or per 1000, or some similar measure. The *incidence rate* is how many new cases there are, while *prevalence rate* is the total number of sick people. *Case fatility rate* is the number of people who die once diagnosed. *Infant mortality rate* and *maternal mortality rate* are common examples among many more. A Dutch epidemiologist wrote a children's book called Daddy counts sick people that sums it up.

All-cause Mortality A key rate which records death from every cause to avoid misclassification and other errors. An important metric in day-to-day epidemiology, it is also the measure of an extraordinary result about vaccines. Studies involving *millions* of people show vaccines reducing death from all causes. Deaths unrelated to the vaccine target (such as accidents, genetics or unknowns) are reduced.

Reproductive Number (R or R_0) This is just a number not a rate: the average number of new infections caused by one case of the disease. The bigger R, the more infectious the disease: winter flu is 0.9-2.1 people on average, while measles is 12-18 people.

Sentinel species These are organisms that signal the presence of pathogens before they affect humans, because in some sense they are in the same environment as humans. For example, beehives sicken from agricultural pesticides that will, years later, cause Parkinson's in humans. Domestic pets suffer from cancer or

obesity before their owners succumb to the same lifestyle causes. And many plants become visibly ill from air pollution in a matter of weeks.

Appendix B Historical steps towards epidemiology

Medical historians have written extensively on epidemiology. This Appendix takes a very different approach, explaining the arrow timeline diagram in What is epidemiology *not just?* My enquiry at each point was **can epidemiology be done?** and as a simple measure I consider whether it is possible to model disease. Modeling is possible if we have surveillance data, which is more than just clinical observations of an individual patient. The US CDC Field Manual [Hedberg and Maher 2024] describes well how data for modelling must have consistent definitions, time-based rates and completeness. The definition of epidemiology constantly evolved during 1970s-2010s[Frérot et al. 2018], which is another reason for just considering the main steps that got us to where we are in 2026.

We have no medical records from the Neanderthal cultures' skillful pro-social healthcare[Spikins et al. 2019] from 250,000- 40,000 years ago. Readers unpersuaded by non-human healthcare can fast-forward to 50,000 years ago when *there is evidence for human engagement in health-related caregiving from at least the middle upper Palaeolithic onwards*[Tilley 2015, chap. 4].

Records exist from 2600 years ago[Buck et al. 1988, chap. 1, p. 3][5]. Sushruta of India's work Smihita[work) 1907] understands infection and is highly rational in its approach, but still has categories for supernatural causality.

200 years later, around 300BCE, Hippocrates' books "Air, Water and Places"[Hippocrates 1849b] and "Epidemics"[Hippocrates 1849a] *removed the concepts of superstition, magic, and religion from medicine*[6]*.. Hippocrates' medicine, in addition to being based on reason, was patient-centered rather than disease-oriented and focused more on observation and experience*[Ameri et al. 2021]. Hippocrates also studied the health of whole populations (although he did not surveille them), coming closer to epidemiology.

We cannot model the behaviour Hippocrates observed. The case notes are impressive, so accurate that medical anthropology has established which two microscopic Plasmodium parasite species caused malaria in Hippocrate's patients[C. B. Cunha and B. A. Cunha 2008]. But they do not contain rates.

Can the much better medical data from ancient Baghdad or China be modelled? Still no.

1300 years after Hippocrates, the Abbasid Caliphate (750 – 1258 CE) had advanced science, engineering and health administration[al-Hassan 1994]. Al-Razi of Bagdhad[Tibi

[5] In fact we have written records from thousands of years earlier, when ancient Egyptians documented their medical practices. They are *very* keen on gods causing illness and so don't help with epidemiology.

[6] This is *Methodological Naturalism*. It is less obvious than it may seem to exclude God-type metaphysical causal explanations from medicine. This takes considerable understanding even today[Donahue 2025]

2006] and his Comprehensive Book of Medicine is covered in the section on One Health. But while Al-Razi has the most extensive case notes of the ancients, even his data is not sufficiently regular to model.

A century later, 1400 years after Hippocrates, in 1000CE China there were state-funded responses to disease, strongly influenced by Indian healthcare practices in previous centuries[7] Chinese society had whole-of-society interventions such as hospitals, food and monetary support, social distancing and mobile medical care. Records tell us about 293 different instances of epidemics[Yi 2015] during the Song dynasty alone (960CE to 1279CE), covering 12 well-described diseases. This data also fails the CDC Field Guide.

400 years later, in 1678, the Kangxi Emperor of China made smallpox vaccination (in the form of variolation, inhaling crushed smallpox scabs) into a public health intervention starting with his own family and scaling up to the military and their families[Kaitai 1590 CE–]. Lacking knowledge of Chinese medicine and concepts such as *Qi* I cannot comment further. A paper on smallpox vaccination in China[Shaoxin 2006] describes the acceptance of superior Western vaccinations over traditional variolation.

This ancient data is better organised than any before it, however we *still* can't model these Chinese epidemics because we lack population behaviour, and the data is still irregular.

The arrival of tabular data that can be used statistically

Scientific medical data appeared in 1750. James Lind may have run the first-ever controlled trial, for the disease scurvy[Lind 1753]. At last we have data tables[*Scurvy Dataset* 2023] that can be used for statistical calculation, in this case in the language R. This is after the style of Evidence-based medicine, which gives falsifiable results we can trust. While not itself modelling, it is a pre-requisite.

Standardised public records begin, 1792. Post-revolution France mandated standardised death certificates[Assemblée législative nationale 1792], preceded by a Swedish state-run system in churches[Hiltunen Maltesdotter and Edvinsson 2025], with Europe-wide standards following in 1855. After **two and a half millennia of epidemiological records unsuitable for modelling** we can finally calculate death and other rates.

Medicine applied to a population, in 1855. London doctor John Snow observed the pattern of deaths in a cholera outbreak, noticing an association with a particular water supply. Snow later published his conclusions[Snow 1855], and over time convinced the local authorities that improved sanitation would solve the problem[8] Snow published tempo-spatial tables[*SnowData Package Manual* 2023] suitable for modelling.

Germ theory of medicine. Louis Pasteur built on the work of previous decades with his theory of microorganisms as causal agents of disease, as (for example) translated in

[7] Much scholarship covers the spread of Indian public health ideas starting two centuries before King Ashoka's time, including ideas including public hospitals for humans and animals, repeatable pharmacology and medical universities. But the Indians did not keep case notes!

[8] There is mythology[McLeod 2000] about Snow, but no evidence a pump handle was removed to stop the epidemic – but it's a great story.

the British Medical Journal[Pasteur 1878] in 1878.

B.1 Modern methods and organisation

Mass-action kinetics applied to epidemics, 1927. Kermack and McKendrick[Kermack and McKendrick 1927] published the first SIR (Susceptible, Infected, Recovered) compartmented model which traces how individuals in a population moves from one state to another. This is a *mechanistic causal model* because we know the reason for a person changing state, for example by recovering from illness. This contrasts with *observational statistics* which reports percentages of the population who recover or die etc. over time, but does not assume underlying causality. Kermack and McKendrick took equations used in chemistry for 50 years. They applied reaction rates to humans as infection (etc.) rates, and solved the system of ordinary differential equations exactly like the chemists do, see Appendix D: *Minimum requirement: mathematics*. This SIR model is the foundation for modern epidemiological calculations.

Randomised controlled trial [*Council 1948*] This study had blinding, consent, good sample size and a control group – all pulled together for the first time. The resulting data was ideal for statistical analysis. However I can find no record of SIR-type modelling being applied to this data at the time, although now that is trivial to do since there is an R dataset[(UK) 2024]. This trial agreed with the scientific method established by Popper et alia [Popper 1934], especially the principle of being falsifiable.

1948 was also when the *World Health Organisation* was founded. WHO embodied leading scientific thought at the time. We considered the question **what was epidemiology like in the early days of WHO?** which lead me to The National Library of Scotland's physical paper collection. One example is the book *Epidemiology of Health*[Galdston 1953] full of illustrations such as school lunches in the UK as a response to health disparity, changing health policy. That feels modern, but on the other hand Galdston discusses "that newest of disciplines, which remains unchristened but which has been ...expounded under the title of *Stress Syndrome*" (ibid. p7). The "nameless discipline" so exciting in 1953 is now the entire fields of neurobiology, psychoneuroimmunology and endocrinology we take for granted.

Publication of [*Anderson and May 1991*], which linked compartmental models such as SIR to data from many different types of epidemics, showing how models can take account of social and disease dynamics. This foundational book showed in simple ways how mathematical modelling and policy can have an effect on each other. From this point on, epidemiology became intimately connected with modelling. Anderson and May is essential to understand mixing of populations, and how clusters become bias if they are not identified and so on.

Publication of [*Lakatos 1970*]. The scientific method was famously founded on the concept of falsification in [Popper 1934] But! This does not match well with modelling of the kind we see in SIR or chemistry mass kinetics. Falsification is essential, but is related to an individual experiment. Models are often about ongoing development and refinement rather than attempting to disprove something. Modelling is well explained by Laktos' idea that science advances through research programmes, not isolated hy-

potheses. Each model in this sense can be a research programme.

B.2 Beginning of modern epidemiology

This is 2026, so I asked **When did modern epidemiology begin?**

Modern epidemiology first appeared around 1800, with the application of early statistical methods to a problem where a lot of data was available, and progressed unevenly over the next 200 years until the 21st century.

The *Introduction* argues epidemiology began around 1950, when for the first time the many factors in medicine made it possible create something new, applying techniques to large populations with spectacular effect.

Appendix C How did Epidemiology forget the environment?

As previously seen, the idea of the environment, animals and humans being co-dependent for their health is an ancient one. And yet, as epidemiology made immense progress in the 20th century, it all seemed to have been forgotten. Perhaps in part this was due to the excitement of germ theory and the rapid advances it enabled. In the West a great deal has been written[Duffy 2011] about the good and the bad that flowed from the 1910 Flexner report in the US and Canada; one of its many problems was a focus human bioscience.

I found it helpful to ask **What was the epidemiological context to the holistic approach of Silent Spring?** This book had such an immense impact in population health that, logically, epidemiology should have been involved. But I found that in 1962 in the US, when the Silent Spring author Rachel Carson applied ecological systems thinking to the problem of ecocide[Carson 1962], this was not the case. Carson was not rigorous, but it seems epidemiology was not yet ready for rigour. Environmental epidemiology did not exist, and Carson was drawing on many fields including toxicology, entomology and plant science – a mashup epidemiology was seemingly not ready to hear according to contemporary accounts. While Carson's success is evident[9] The Silent Spring Institute[Institute 2025] was founded in 1994 to conduct rigorous research inspired by Carson's book, which implicitly supports my view here. The founding of the US EPA can be viewed in part as a challenge to epidemiology, not a success due to it.

Conclusion: while the environment was for previous millennia seen as part of population health, in the twentieth century giant medical biomedical advances seem to have squeezed this out.

I asked **How does WHO see the environment?** The WHO constitution[WHO 1948] is compatible with Hippocrates: "Health is a state of complete physical, mental and

[9] The US Environmental Protection Agency was founded within a decade and credit is given to Silent Spring for this, despite the bitter opposition Carson faced *including from epidemiologists.*

social well-being and not merely the absence of disease or infirmity." WHO assumes that environment in the broadest sense affects either disease or limits well-being.

Tentative conclusion: It seems like the promising inclusive approach at the founding of WHO was somewhat derailed, but is now firmly back on track with One Health.

C.1 What exactly happened?

[In brief – Biomedical models became more prominent than policy advice.]

Epidemiologists provide input to societal policy decisions, presenting choices for disease management and health promotion. Most epidemiology papers I read seemed narrowly focussed on bio-statistics, not closely aimed at guiding policy. There are some seminal high-impact papers but I wondered **How can epidemiology guide public policy if scholarship tends to avoid policy implications?**

Tentative conclusion: It can't really, necessitating additional interpretive steps. Such steps clearly do happen, as seen in NHS guidance, but it seems an indirect route. The UK COVID-19 hearings 2025-2026 demonstrate how epidemiology had less effect than it might, with a calamitous numbers of avoidable deaths.

I stepped back a bit further and asked **What do epidemiologists say about their own field?**. I discovered some highly interesting epistemological discussions, regrettably beyond the scope of the current paper. Critiques of thinking patterns such as "Biological Reductionism",[Rivas et al. 2017], "Black-box Epidemiology"[Weed 1998], and "Epidemiology linked to Health Inequalities"[Beckfield and Krieger 2009] show that some epidemiologists have been calling for a wider approach for decades. None of this voluminous critical literature tries to invalidate traditional epidemiology, the contention is more that it is insufficient to ignore biological causality or complex systems interactions.

I suspect there is a connection with what Judea Pearl called the "Causality Crisis" [Pearl and Mackenzie 2018], where statistics became fixated on the challenge of causality at the expense of structural considerations. Epidemiologists until the 1970s famously found it difficult to say that smoking causes cancer because a randomised controlled trial would be unethical (since it would assign smoking to one group for 30 years and another to the intervention of non-smoking.) All the scientists could do was *observe correlations* using statistics, but in order to mathematically prove causation something else was needed. Pearl argues that the delay in officially concluding that smoking causes lung cancer was a failure of mathematical vocabulary.

Judea Pearl's do-calculus goes beyond the conditional probability of statistics which states $P(\text{Cancer} \mid \text{Smoking})$, or "What is the probability of cancer among people who happen to smoke?" This is vulnerable to hypotheses such as a gene for smoking – if such a thing existed it might influence both the desire to smoke and the risk of cancer. And in that case, cancer would be caused (or mediated) by the gene, not by the smoking.

With Pearl's **do-operator** we can instead ask a counterfactual question: "What would

the probability of cancer be if we forced the entire population to smoke, regardless of their genetic predisposition?" or $P(\text{Cancer} \mid do(\text{Smoking}))$. The full details are beyond the scope of this paper, but Pearl showed that using a Directed Acyclic Graph (DAG) and the Front-Door Criterion, one could mathematically prove the causal link using observational data alone by looking at intermediate variables like tar deposits.

Thus epidemiology's main tool had a major causality problem until Pearl, and perhaps this is what held back epidemiology from considering the greatly increased complexity of a system-of-systems approach. When it comes to One Health, Pearl's approach makes it possible to handle complex environmental confounders such as effects from climate change. Later work, especially [Jaber et al. 2022],has allowed computation of the more realistic scenario of an incomplete causal diagram.

Appendix D Minimum requirement: mathematics

D.1 Foundation: From Chemistry to Epidemiology

The mathematical foundations of epidemiology come directly from chemical kinetics. There are three fundamental concepts:

1. **The Master Chemical Equation**: A system of differential equations describing how reaction rates relate to concentrations over time while preserving mass. Though reactions at the molecular level are inherently random, with vast numbers of particles the deterministic approximation holds remarkably well.
2. **Gillespie's Stochastic Algorithm**: Addresses the computational challenges when particle numbers are small (such as reactions within a single cell, or the initial "spark" of an outbreak). This discrete, probabilistic approach computes individual particle interactions using the rate constants from the master equation.
3. **Exponential Distributions**: Both deterministic and stochastic approaches assume reaction waiting times follow exponential distributions—a simplification that proves computationally tractable even when not entirely realistic.

D.2 Deterministic Models: The SIR Framework

In 1927, Kermack and McKendrick[Kermack and McKendrick 1927] published the foundational SIR (Susceptible-Infected-Recovered) model, treating populations as chemical reactants. For large populations, individual randomness averages to smooth, continuous curves:

Chemical Reaction (A + B → C):
$$\begin{cases} \frac{d[A]}{dt} = -k[A][B], \\ \frac{d[B]}{dt} = -k[A][B], \\ \frac{d[C]}{dt} = k[A][B] \end{cases}$$

SIR Infection (S + I → 2I):
$$\begin{cases} \frac{dS}{dt} = -\beta SI, \\ \frac{dI}{dt} = \beta SI - \gamma I, \\ \frac{dR}{dt} = \gamma I \end{cases}$$

Here β is the transmission rate and γ the recovery rate. The deterministic assumption (that smooth curves adequately describe population dynamics) works when numbers are large but fails for small populations or during outbreak initiation.

[Anderson and May 1991] became the definitive text linking compartmental models to empirical epidemic data for many diseases, demonstrating how mathematical formulations can express social and biological dynamics. Their work established ordinary differential equations (ODEs) as the standard language of epidemiology.

D.3 Stochastic Models: The Gillespie Algorithm

When populations are small or discrete events matter (such as "patient zero", or a zoonotic event), deterministic ODEs fail. The Gillespie algorithm[Gillespie 1977] (also called the Stochastic Simulation Algorithm, SSA) provides exact solutions to the master equation by sampling individual reaction pathways.

For the SIR model, the algorithm computes:

$$\begin{aligned} a_1 &= \beta SI \quad \text{(infection propensity)}, \\ a_2 &= \gamma I \quad \text{(recovery propensity)}, \\ a_0 &= a_1 + a_2 \quad \text{(total propensity)}, \\ \tau &= \frac{1}{a_0} \ln\left(\frac{1}{r_1}\right) \quad \text{(time to next event)}, \end{aligned}$$

Choose reaction μ where $\sum_{j=1}^{\mu-1} a_j < r_2 a_0 \leq \sum_{j=1}^{\mu} a_j$

Here r_1 and r_2 are uniform random numbers in [0,1]. The algorithm:

1. Calculates when the next event occurs (τ)
2. Determines which reaction happens (infection or recovery)
3. Updates population counts

4. Repeats

Unlike ODEs which give a single trajectory, Gillespie produces a distribution of possible futures. Outbreaks are uncertain, and a probability distribution informs the discussion of what to invest, when and where.

D.4 Beyond Compartmental Models: Agent-Based and Rule-Based Approaches

Classical SIR models assume homogeneous mixing: every susceptible person has equal contact probability with every infected person. Humans are not chemical molecules, so this assumption often fails due to:

- Spatial structure (geographical spread)
- Heterogeneous contact networks (households, workplaces, schools)
- Individual variation (age, immunity, behaviour)
- Vector-borne diseases (mosquitoes, ticks)
- Environmental factors (temperature, land use, animal reservoirs)

This is where we find the big problem with the compartmental model. Where there are four compartments, we can write ODEs for each of the possibilities. But consider malaria, for example, where a mosquito may be infected or uninfected, just like a human. This means that we have to additional S and I compartments for mosquitoes, meaning four more ODEs. This continues for every new variable we introduce: bednets yes/no, age old/young/middle, and so on. This is a combinatorial explosion and quickly becomes impossible. One Health has a huge scope that makes this problem even worse.

There are two ways of approaching this:

Agent-Based Modeling (ABM): Represents each human, animal, or pathogen as a discrete entity with individual state variables. Agents interact according to specified rules, generating emergent population-level patterns. Computationally intensive and therefore subject to different, combinatorial explosion at a higher limit than ODEs. It does capture heterogeneity and spatial structure.

Rule-Based Modeling (RBM): Defines interaction rules without enumerating all possible states. For example: *IF human is within 10m of infected vector AND vector bites, THEN human becomes exposed at rate* β. This allows complex multi-scale dynamics (cellular to ecosystem) without the explosions.

Both approaches extend beyond the chemical kinetics analogy, though they retain the probabilistic foundations. They are essential for One Health modeling where traditional epidemiology (humans only) must integrate with veterinary surveillance, vector ecology, climate drivers, and land-use patterns.

Even if an overly complex model can be computed, it is distinctly possible that the results will not be useful. For this reason, epidemiologists emphasise selecting only relevant parameters to avoid obscuring useful results in the noise. This also helps the combinatorial problem, even with ODEs.

D.5 Parameter Estimation and Model Calibration

All models require parameter values (β, γ, contact rates, etc.). These are estimated through:

- **Fitting to outbreak data**: Using statistical methods (maximum likelihood, Bayesian inference) to find parameters that best match observed case counts
- **Contact studies**: Measuring actual human interaction patterns through surveys or digital tracking
- **Laboratory measurements**: Determining pathogen characteristics (infectivity, survival times)
- **Sensitivity analysis**: Testing how results change across plausible parameter ranges

One Health makes these challenges more difficult. Human disease parameters are often difficult to find, and animal reservoir dynamics, vector behavior under climate change, and cross-species transmission rates tend to be much more sparse. Model uncertainty quantification becomes critical.

Parameter estimation is one place where Bayes Theorem is important: $P(A|B) = \frac{P(B|A)P(A)}{P(B)}$. In parameter estimation we can think of this as *Posterior* = (*Likelihood* × *Prior*) / *Evidence*, which is very helpful for solving the inverse parameter problem — there is an event happening and we can measure what is happening but we don't know how likely the input parameters are.

Bayes is also helpful for selecting between models with different numbers of parameters, probabilistic forecasting and updating estimates in real time (because Bayes algorithms are constantly updating themselves with the information from the previous step anyway.) The specific application of Bayes to epidemiology is a large subject and it is sufficient to know that it underpins much of what happens with data and parameters outside the models.

D.6 Policy implications of models

Mathematical models inform public health decisions:

- Epidemic forecasting (hospital capacity planning)
- Intervention evaluation (vaccination strategies, lockdowns)

- Scenario analysis (what-if questions about policy choices)
- Resource allocation (where to deploy limited supplies)

Models can only formalise assumptions, making the reasoning explicit and testable. In One Health, models must now integrate across timescales (hours for clinical response, years for ecological change), spatial scales (subcellular to continental), and knowledge systems (laboratory virology, traditional veterinary practice, indigenous land management). This is where mathematical epidemiology is challenged to meet the complexity of real-world health systems, and the data which all the new scientists are bringing with them.

Appendix E US withdrawal from WHO and One Health

Epidemiology is inherently political in its goals, and One Health even more so. In 2025 the US withdrew from WHO[Buse et al. 2025], formally completed in January 2026. This is a destabilising blow and the impacts have been discussed in the literature. To illustrate that the first concern is not funding, consider that the US was absent from the first-ever adoption of One Health into international law:

- The WHO Pandemic Agreement is a global treaty on pandemic prevention, preparedness and response
- Launched in response to failures exposed by COVID-19
- Article 1(b) defines One Health, and Articles 4 and 5 discuss land use, food systems, wildlife, antibiotic use etc
- Passed in May 2025 by 134 countries at the 78th World Health Assembly

This is a disaster, not an own goal, but an everyone-goal. Viruses do not respect borders, meaning the US cannot isolate itself in reality by isolating itself politically.

Science community responses range from *...an attack on multilateralism and its institutions that develop and implement global rules, standards and norms ...modelling studies across various disease control programmes indicate potential adverse health effects for millions.*:[Franz and Bozorgmehr 2025] to *One Health cannot function when its largest funder walks out mid-crisis*[Ortiz-Prado et al. 2025]. In January 2026 *Nature* published the first of a four-part series on the destruction the US has already caused by the withdrawal[Nature 2026].

There are many complexities. As to health-related aid for developing countries, African voices have been consistent that a return to pre-Trump aid is not desirable even if it were possible:

> *Any continuing or new donor initiative cannot take the same inefficient approach as before. Donors should invest in underlying healthcare systems to make vertical programmes, targeting specific populations or diseases ...How the global public understands and talks about aid – as charity instead of reparation for colonial era and contemporary injustice – also needs to change. Aid often comes with conditions, including requiring aid recipients to source goods and services from the donor country. Donor countries often benefit as much if not more than recipients, as aid supports their own economies and access to markets and global political influence.*

— ["After USAID: what now for aid and Africa?" 2025]

The funding is of course Ronald G. Nahass, IDSA President, Jan 22 2026significant at least in the short term. Between 2019 and 2022, the United States accounted for approximately 45programmes such as USAID as well as WHO. No countries or organisations have indicated they will make up the shortfall. Some replacement funding has been mobilised (much of it from China), but as of January 2026 there does not seem to be any coordinated plan for how health progress is to be made.

Nevertheless, there have been some rapid changes. Global health is becoming more multilateral, and peak bodies seem even more focussed on One Health. This urgent and scathing statement from November 2025 captures the mood, going head-to-head with the US approach:

> *We hereby reaffirm our commitment to advancing the One Health approach ...high burdens of zoonotic disease outbreaks ...persistence of neglected zoonoses ...irrational uses of antibiotics in health care and agriculture ...requiring whole-of-government, whole-of-society approaches, including the effective engagement of the private sector.*

— the Quadripartite Statement of peak bodies in Africa

Similar political statements come from the European Union representatives[EJP 2026], and the African Union[AU-IBAR 2025]. The Association of Southeast Asian Nations (ASEAN) committed to One Health in 2023[Leaders 2023], and have continued to support new multilateral health programmes even as the US leaves them.

Some US scientists have been outspoken:

> *Withdrawing from the World Health Organization is scientifically reckless.*

— Ronald G. Nahass, IDSA President, Jan 22 2026

In brief, perhaps the US withdrawal and general anti-health attitude represents an opportunity, but in the short term it will cost lives and slow progress.

Scientists coming in to One Health cannot avoid this giant political problem.

Appendix F What kind of organisation is One Health?

One Health operates as a multi-sectoral collaborative governance framework rather than peer production:

Institutional Hierarchy: The WHO One Health Initiative uses a Steering Committee for strategic leadership and resource allocation, with a Technical Team ensuring regional coordination . National implementations often sit within Ministries of Health with top-down policy flows .

Co-production ≠ Peer Production: While One Health uses "co-production" of knowledge (engaging stakeholders in participatory workshops), this is stakeholder consultation within institutional frameworks, not the decentralized, commons-based creation of shared resources seen in CBPP . Geopolitical Power Structures: Bibliometric analysis shows One Health research networks are dominated by Global North institutions, with Global South actors often marginalized despite the rhetoric of inclusivity . This contrasts with CBPP's meritocratic, open-access ethos. Professional Boundaries: Unlike CBPP's "permissionless" participation, One Health maintains strong professional hierarchies (veterinary dominance, medical authority) and disciplinary silos .

Where Peer Production Appears in Health Contexts True CBPP in healthcare looks different. The research identifies ImproveCareNow (a pediatric inflammatory bowel disease network) as an example of peer production in health—where patients, families, and clinicians collaboratively generate knowledge without hierarchical control, sharing data openly and making decisions through consensus . Some specific One Health projects might incorporate peer production elements (such as open-data disease surveillance platforms), but the One Health movement as a whole operates through collaborative governance—balancing hierarchical coordination with cross-sectoral partnership . Conclusion One Health is better understood as a polycentric governance structure (in the Ostrom tradition)—multiple centers of decision-making across sectors and nations, often coordinated through formal institutional mechanisms . While it challenges purely siloed, hierarchical health governance, it does not meet the criteria for Commons-Based Peer Production, which requires the absence of formal organizational hierarchy, open contribution without institutional gatekeeping, and commons-based licensing of outputs . Key distinction: One Health is collaborative, but it is institutionally coordinated collaboration; CBPP is spontaneous, decentralized peer coordination.

To analyze "One Health" and similar network-level organizations, we must move beyond traditional firm-based hierarchies. The following three frameworks provide the socio-technical and polycentric logic required to understand decentralized networks.

F.1 Commons-Based Peer Production (CBPP)

Yochai Benkler (2006) defines *Commons-Based Peer Production* as a distinct socio-economic model of production emerging in the digitally networked environment. Unlike the

"Cathedral" model of top-down command, CBPP thrives on the decentralized action of individual agents. For a network like One Health to mirror a CBPP model, it must satisfy two structural conditions:

- **Modularity:** Objectives (e.g., pathogen surveillance) must be divisible into components produced independently.
- **Granularity:** Modules must vary in size to allow for heterogeneous levels of contribution, minimizing entry costs.

F.2 Polycentric Governance

Elinor Ostrom's (1990) theory of *Polycentricity* posits that complex systems can be governed by multiple, overlapping decision centers possessing semi-autonomous authority. In the context of One Health:

$$G = \{C_1, C_2, \ldots, C_n\} \text{ s.t. } \bigcap C_i \neq \emptyset \tag{1}$$

Where G represents total governance and C_i represents individual centers (e.g., WHO, national ministries). The system relies on "nested enterprises" where local knowledge is integrated into global standards without a single monolithic coordinator.

F.3 The Network Administrative Organization (NAO)

Provan and Kenis (2008) identify the *NAO* as a specific evolution of the Shared-Governance Network. While a "Bazaar" is organic, an NAO is a separate entity established specifically to govern the network. This highlights a critical trade-off:

Governance Mode	**Efficiency**	**Inclusiveness**
Shared Governance (Bazaar)	Low	High
Lead Organization (Cathedral)	High	Low
NAO (One Health Secretariat)	Medium	Medium

Table 1: Governance Trade-offs in Network-Level Organizations

F.4 Synthesis: From Raymond to Benkler

While the practitioner-led "Bazaar" model (Raymond, 1999) provided the initial metaphor for decentralization, Benkler' s CBPP provides the formal mechanism. One Health operates as a "Bazaar" of data, but its sustainability is governed by the rules of the "Commons," where the primary hurdle is the **Collective Action** problem of free-riding.

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