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Authors

Fieldhouse, Jane K
Randhawa, Nistara
Fair, Elizabeth
et al.

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One Health timeliness metrics to track and evaluate outbreak response reporting: A scoping review

Jane K. Fieldhouse,[a,b] Nistara Randhawa,[b] Elizabeth Fair,[a,c] Brian Bird,[b] Woutrina Smith,[b] and Jonna A.K. Mazet[a,b]**

[a]Institute for Global Health Sciences, University of California, San Francisco, California, USA
[b]One Health Institute, University of California, Davis, California, USA
[c]Division of Pulmonary and Critical Care Medicine, Department of Medicine, University of California, San Francisco, California, USA

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Summary

Background As the global population soars, human behaviours are increasing the risk of epidemics. Objective performance evaluation of outbreak responses requires that metrics of timeliness, or speed in response time, be recorded and reported. We sought to evaluate how timeliness data are being conveyed for multisectoral outbreaks and make recommendations on how One Health metrics can be used to improve response success.

Methods We conducted a scoping review of outbreaks reported January 1, 2010– March 15, 2020, in organizational reports and peer-reviewed literature on PubMed and Embase databases. We tracked 11 outbreak milestones and calculated timeliness metrics, the median time in days, between the following: 1) *Predict*; 2) *Prevent*; 3) *Start;* 4) *Detect*; 5) *Notify*; 6) *Verify*; 7) *Diagnostic*; 8) *Respond*; 9) *Communication*; 10) *End*; and 11) *After-Action Review*.

Findings We identified 26783 outbreak reports, 1014 of which involved more than just the human health sector. Only six of the eleven milestones were mentioned in >50% of reports. The time between most milestones was on average shorter for outbreaks reporting both *Predict* (alert of a potential outbreak) and *Prevent* (response to predictive alert) events.

Interpretation Tracking progress in timeliness during outbreaks can focus efforts to prevent outbreaks from evolving into epidemics or pandemics. Response to predictive alerts demonstrated improved expediency in time to most milestones. We recommend the adoption of universally defined One Health outbreak milestones, including *After Action Review*, such that timeliness metrics can be used to assess outbreak response improvements over time.

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Keywords: Outbreaks; Pandemic preparedness; Timeliness metrics; One Health

Introduction

As our global population rapidly approaches eight billion, driving forces, such as globalization, climate variability, and changing use of land, have contributed to increasingly complex, intractable risks to the health of humans, animals, plants, and our ecosystems. For decades, experts have warned of the threat of emerging diseases, driven in large part by human behaviours. For example, increasing frequency and speed of travel has resulted in a record number of people, animals, and goods circulating the globe and coming into contact with one another.[1] As disease outbreaks occur with increasing frequency and intensity,[2,3] what begins as a geographically-isolated health event can quickly evolve to become a regional epizootic, epidemic, or pandemic. One Health is a multi-sectoral, transdisciplinary approach that recognizes that the health of animals, humans, plants, and our shared environment are interdependent.[4] Successful control of diseases across these sectors requires a coordinated effort to shorten the time between outbreak milestones, such as the start of an outbreak or even predictive alerts signalling a potential outbreak and all subsequent milestones that occur during the investigation and response. Speed in outbreak

*Corresponding authors at: One Health Institute, 1089 Veterinary Medicine Drive VetMed 3B, Ground Floor West, Davis, CA 95616, USA.
E-mail addresses: jane.fieldhouse@ucsf.edu (J.K. Fieldhouse), jkmazet@ucdavis.edu (J.A.K. Mazet).

Research in context

Evidence before this study

This study was inspired by the development of One Health timeliness metrics at the Salzburg Global Seminar by a group of renowned global experts in outbreak response. To examine metrics in use, as well as to identify gaps in tracking capacities, this scoping review searched literature published between January 1, 2010, and March 15, 2020, using the search terms "outbreak" in the title and "research report", "research", "report", "describe", or "summarize" in the article abstract or body. The search yielded 26783 reports, of which, 1014 met our inclusion criteria.

Added value of this study

This study builds upon past analyses of timeliness metrics during outbreaks occurring among humans to consider trends during outbreaks involving the animal, environmental, human, or plant sectors. Outbreaks that reported dates of both an alert of a potential outbreak and a response to that predictive alert had, on average, shorter median times between milestones.

Implications of all the available evidence

A comparison of the findings of this review and past analyses of timeliness metrics trends demonstrates the need for the adoption of universal outbreak milestones and definitions such that baseline metrics on outbreak timeliness performance can be uniformly measured and objectively evaluated. Milestones related to predictive alerts of and preventive responses to potential outbreaks should be tracked to support efforts to shorten detection and response times.

detection and aetiology identification is essential to executing more successful responses, potentially averting unnecessary morbidity and mortality in human and animal populations, while additionally reducing the economic and societal consequences of an outbreak and necessary control measures.

To understand trends in how quickly we detect and respond to disease outbreaks and human, animal, environmental, and plant health alerts, countries must have established baseline metrics to measure timeliness in outbreak detection and response. Such metrics have been proposed to systematically capture human outbreak timeliness data;[5] however, no standardized benchmarks have been universally adopted to-date. Building upon these metrics, a multidisciplinary team of experts from around the globe gathered in 2019 to develop a set of One Health timeliness metrics for epidemic preparedness to serve as standardized measures during outbreaks involving the animal, environmental, human, or plant sectors.[6] These timeliness metrics, outlined in the Salzburg Statement, are defined as the intervals between two respective outbreak milestones that occur during an outbreak.[7] Examples of timeliness metrics include the interval between the date an outbreak starts and the date of an official release of information to the public, or, similarly, the interval between the date relevant authorities are notified of an outbreak and the date of a diagnostic test or laboratory confirmation. The One Health timeliness metrics, along with 11 clearly defined outbreak milestones, were released in May 2020, coinciding with increasing awareness worldwide of the critical need for a One Health approach to epidemic preparedness.[7]

While the One Health timeliness metrics were devised before the global arrival of COVID-19, the pandemic has exemplified the threat of emerging infections and reinforced the need to leverage a collaborative, multidisciplinary approach to preventing and responding to disease outbreaks.[8] Countries worldwide have seen the effect of speedier detection and response times to COVID-19 manifested as cases averted and lives saved.[9,10] Too many regions have also witnessed the consequence of slow detection and response, which contributes to high case numbers and mortality. We can and must do better to improve the preparedness, prevention, detection of, and response to outbreaks. For this reason, we sought to analyse the use of key One Health outbreak milestones for responses reported between 2010 and 2020 to establish an important evidence base for future outbreak response recommendations.

Methods

Scoping review

Given the breadth and diversity of One Health-related outbreaks and surveillance reports, we opted to synthesize the body of literature using a scoping review.[11,12] The methodology and process of this review have been documented per the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines Extension for Scoping Reviews.[13,14]

Inclusion and exclusion criteria

The initial literature screening included reports published between January 1, 2010, and March 15, 2020. All outbreaks meeting selection criteria involved two or more One Health sectors (human, animal, environmental, or plant health) or, particularly for outbreaks of unknown aetiologies, prompt investigation due to concern regarding two or more sectors. Reports included peer-reviewed publications on outbreak events and outbreak reports published by internationally recognized agencies or organizations, namely the U.S. Centers for Disease Control and Prevention's (CDC) Morbidity and Mortality Weekly Report (MMWR)[15], the World Health

Organization's (WHO) Disease Outbreak News (DON) reports, and the International Society for Infectious Diseases' Program for Monitoring Emerging Diseases (ProMED) posts.[16] We also included outbreak reports from a United States Agency for International Development (USAID)-funded project as a programmatic case study.[17] Within each reporting outlet, if there were multiple reports of the same outbreak event in any given year, only the last comprehensive report published on that outbreak was included in the analysis. If an outbreak spanned several years, the last report from each of those years was included in the final analysis. Additional details on inclusion and exclusion criteria can be found in the Supplemental Appendix.

Peer-reviewed literature search strategy

We conducted a search of outbreak reports published in peer-reviewed journals on PubMed and Embase databases. Pre-identified outbreak reports were used to validate the search, which required the term "outbreak" appear in the title and "research report", "research", "report", "describe", or "summarize" in the article abstract or body (Supplemental Appendix). All publications deemed eligible based on titles were reviewed in full for inclusion and exclusion to determine the final set of eligible outbreak reports to be included in the analysis.

Agency and Organizational Reports Search Strategy

Using the archives of the MMWR Weekly Past Volumes and WHO's DON reports, titles were screened to identify all potentially One Health-related outbreak events. Reports were then reviewed in full for eligibility to be included the final review. To access the archives of ProMED reports, we used R[18] to programmatically search and retrieve URLs of posts published with the term "outbreak". All potentially One Health-related topics, including diseases (e.g., "brucellosis"), pathogens (e.g., "*E. coli*" or "EHEC") and health conditions (e. g., "encephalitis"), were included for the eligibility review. Additionally, all "undiagnosed" or "unexplained" diseases and "die-off" events were included for the eligibility review. Due to the volume of posts on the ProMED platform, an additional set of inclusion and exclusion criteria was applied for foodborne illnesses, as described in the Supplemental Appendix.

PREDICT case studies

To understand how outbreak investigations occurring at a project level have reported timeliness metrics and how future projects can improve upon the use of these metrics, our scoping review included a case study of the USAID-funded 11-year global effort[17] aimed at building and strengthening One Health collaborations to detect, diagnose, and respond to epidemic threats.[17,19,20] These PREDICT Outbreak or Health Event Rapid Reports were deemed eligible for full review based on the same inclusion and exclusion criteria as all other reports. For purposes of consistency, we included and analysed reports written from 2017 onward, the year that the project developed a new reporting template for outbreak investigations. These reports detail outbreak or health events for which the country involved requested active support and events for which PREDICT provided support or was on standby.

Data management

Data from all outbreak reports, including report year and source, were extracted and organized using REDCap version 10.0. Outbreaks were categorized as taking place in a single country, multiple (two to five) countries, occurring widely (across more than five countries but not globally), or worldwide. The WHO region of the outbreak described was also recorded. Outbreak reports were classified as a national investigation (i.e., investigated by the country's ministry of health or agriculture and livestock, a research institute, university, etc.), an international investigation (i.e., by a foreign institution), an international response assisted by an outside organisation in collaboration with the affected country, or vague if the origins of the investigation were unclear.

During data extraction, we documented which sectors were involved in the outbreak. For all outbreaks of known aetiology, we documented the transmission route and type of pathogen or parasite implicated in the outbreak as virus, bacteria, parasite, fungus, prion, or toxin. Additionally, we captured whether the report utilized the term "One Health", either by name or implied due to the inherent nature of the investigation.

For each report, we recorded the use of each of the 11 One Health outbreak milestones[7]: 1) *Predict*, a valid alert of a potential health threat; 2) *Prevent*, enhanced surveillance initiated in response to a predictive alert; 3) *Outbreak Start*, the earliest epidemiologically-linked symptom onset or death; 4) *Detect*, the date of symptom onset, death, or evidence of circulation in humans or animals; 5) *Notify*, the official report to relevant authorities; 6) *Verify*, confirmation by field investigation or other valid method; 7) *Diagnostic Test* or lab confirmation; 8) *Respond*, when an intervention was enacted; 9) *Public Communication*, date of the official release of information to the public; 10) *Outbreak End*, when the outbreak was declared closed by a responsible authority; and 11) *After-Action Review*, when a joint review of the outbreak occurred by relevant One Health authorities.

We captured whether a milestone was described with a specific date (a day within a month of a year) or a vague date, such as an epidemiological week. We also captured if a milestone was mentioned but without a date, or if the milestone was not mentioned at all. All milestones reported, however specific or vague, were recorded during data extraction. For the *Diagnostic* milestone, we additionally recorded if an outbreak report described a specific date for diagnostic testing that was unsuccessful, recognizing that even for those outbreaks with unconfirmed aetiology, the milestone was addressed. All data were exported to STATA version 16·0 (StataCorp, College Station, TX) for descriptive analyses and to calculate timeliness metrics, which we defined as the median time in days between two respective milestones.

Ethics

Ethical approval was waived for this study given the nature of the study design.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. All authors had full access to all data in the study and had final responsibility for the decision to submit for publication.

Results

Across all reporting outlets, a total 1014 outbreak reports were included in the final analysis (Figure 1, Supplemental Figure 1). Peer-reviewed publications constituted 14·4% (*n*=146) of included reports, WHO reports 12·0% (*n*=122), MMWR 10·3% (*n*=105), PREDICT 3·2% (*n*=32), and ProMED 60·1% (*n*=609) (Figure 1). Over three quarters of the reports (77·0%, *n*=781) were on single-country outbreaks, 15·9% (*n*=161) involved multiple countries, 4·0% (*n*=41) more widely, and 2·7% (*n*=27) worldwide. Though outbreaks could occur across multiple WHO regions, 381 of the reported outbreaks included in the analysis occurred within the Region of the Americas (PAHO; 37·6%), followed by 225 in the European Region (EURO; 22·2%), 199 in the African Region (AFRO; 19·6%), 152 in the Western Pacific Region (WPRO; 15·0%), 94 in the South-East Asia Region (SEARO; 9·3%), and 64 in the Eastern Mediterranean Region (EMRO; 6·3%; Figure 2). Two thirds (67·4%, *n*=684) of the outbreaks were national investigations, and most other reports (21·3%, *n*=216) described national investigations supported by collaborative international response assistance.

The most common combination of sectors involved in the outbreak reports was animal, environment, and human (35·3%, *n*=358), followed by animal and human (29·8%, *n*=302; Figure 2). The most common route of transmission was direct contact (48·3%, *n*=490), followed by foodborne (26·9%, *n*=273), vector-borne (19·3 %, *n*=196), waterborne (18·0%, *n*=183), or airborne (10·4%, *n*=105) transmission. Eighty-two (82) of the outbreak reports described an outbreak of unknown aetiology (8·1%). Thirty-seven (37) of these 82 (45·1%) noted a presumed aetiology, which we used to categorize the pathogen. Over forty percent (41·5%, *n*=421) of included outbreaks were caused by viruses and 35·4% (*n*=359) by bacteria. Parasites (7·1%, *n*=72), toxins (6·2%, *n*=63), fungi (4·7%, *n*=48), and prions (0·6%, *n*=6) constituted the rest. Just under 4% (*n*=38) of analysed reports specifically mentioned One Health by name.

Analysis of timeliness metrics

The least reported milestone was *After-Action Review*, a metric included in the Salzburg Statement with the intent to “inspire the necessary collaborations among sectors for operationalizing One Health”.[7] Five reports (0·5%) provided a specific date when a joint review of the outbreak occurred, but over 96% (*n*=978) of reports made no mention of such a collaborative review (Figure 3, Supplemental Table 2). A quarter of all reports described a *Predict* milestone, with 49 reports (4·8%) providing a specific date of a predictive alert of a potential outbreak. Only 6% (*n*=59) of reports mentioned the *Prevent* milestone, with 1·1% (*n*=11) providing a specific date of enhanced surveillance or another intervention in response to a predictive alert.

The milestone most frequently described was *Detect* (90·6%, *n*=918) with 45·1% (*n*=457) of all reports providing a specific date of symptom onset or death, 35·2% (*n*=357) providing a vague date, and 10·3% (*n*=104) just mentioning the milestone (Supplemental Table 2). The *Outbreak Start* milestone dates frequently aligned with *Detect* dates with 41·1% (*n*=417) of all reports providing a specific outbreak start date, 37·1% (*n*=376) providing a vague date, and 8·4% (*n*=85) mentioning the *Outbreak Start* (Figure 3). Fewer reports described the *Outbreak End* milestone, with 77·2% (*n*=783) of all reports making no mention of when the outbreak was declared over. Because we did not capture whether the outbreak had ended at the time the report was disseminated or published, we do not know what proportion of these reports omitted *Outbreak End* because the outbreak was ongoing. Approximately three quarters of all reports described the *Verify* (75·8%, *n*=769) and *Diagnostic Test or Lab Confirmation* (76·9%, *n*=780) milestones, either specifically, vaguely, or in mention without a date. Under half of all reports described the *Notify* milestone (46·4%, *n*=471), while 57·7% (*n*=585) of reports described the *Communication* milestone (Figure 3). Of note, several outbreak reports included in our analysis explicitly justified the exclusion of a specific outbreak milestone (Supplemental Appendix).

When reports provided specific dates for multiple milestones, we calculated timeliness metrics, the median time in days between two respective milestones (Figure 4). The two milestones most frequently reported together with specific dates were *Detect* and *Outbreak*

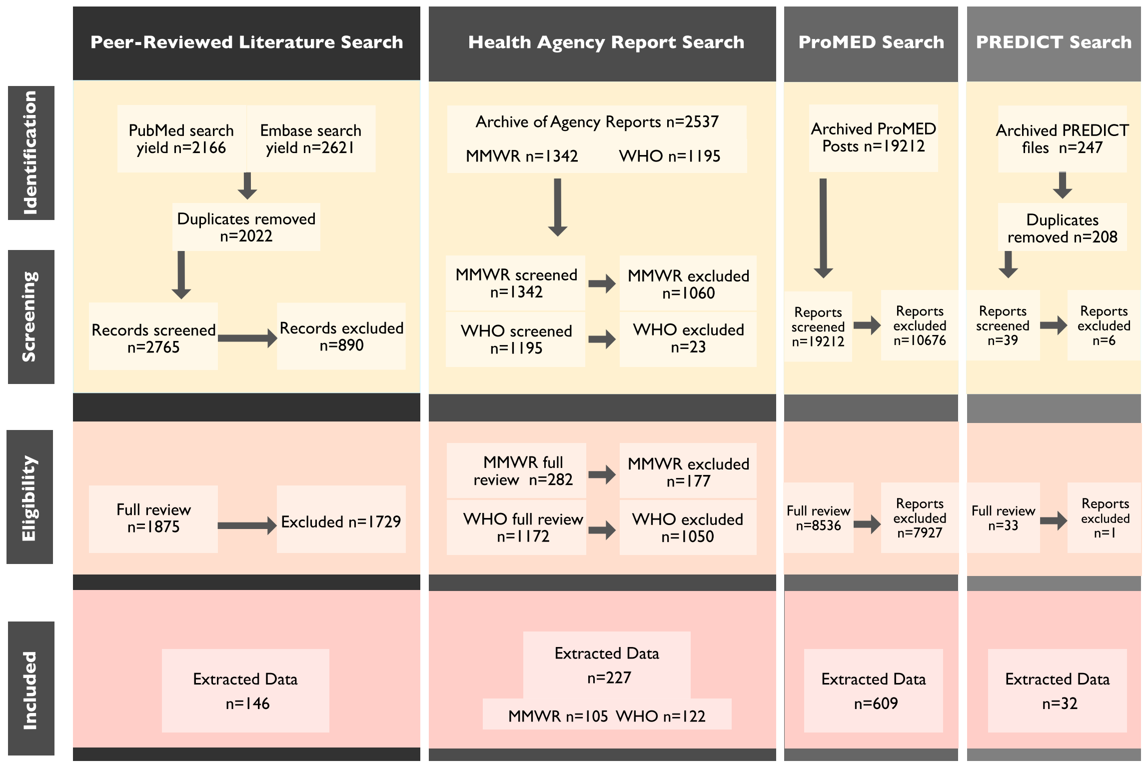

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analysis [13] flow diagram of search and selection strategy for scoping review of timeliness metrics. All outbreak reports identified, screened, and considered for inclusion in the scoping review were published January 2010-March 2020.

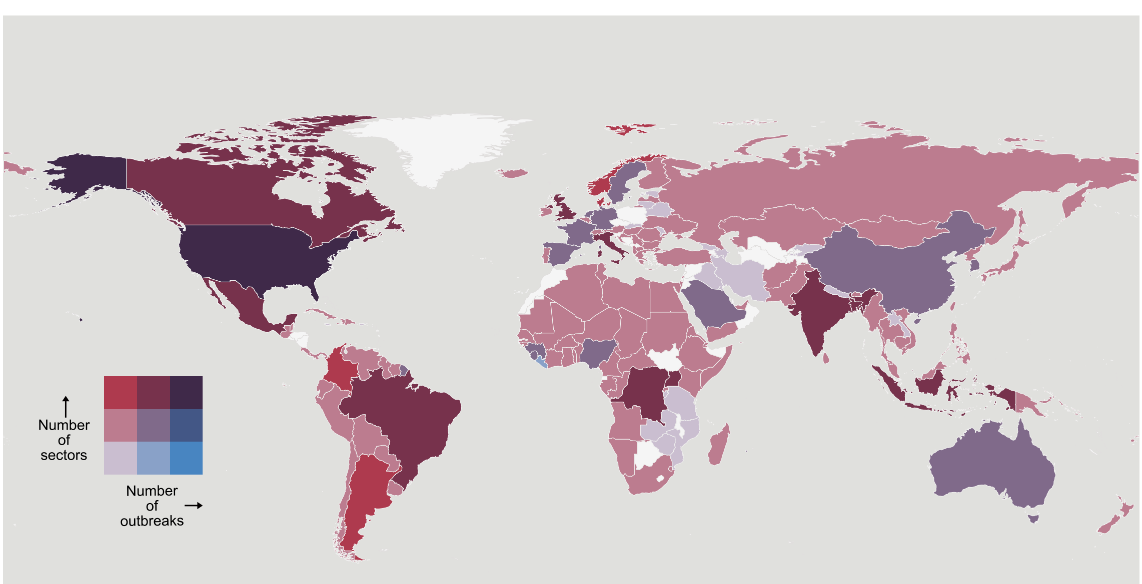

Figure 2. Map of outbreaks reports included in final scoping review analysis by number of One Health sectors involved in outbreaks. Map colour gradient depicts the number of outbreaks as well as the number of sectors involved in each outbreak ranging from two to four of the One Health sectors: animals, the environment, humans, and plants.

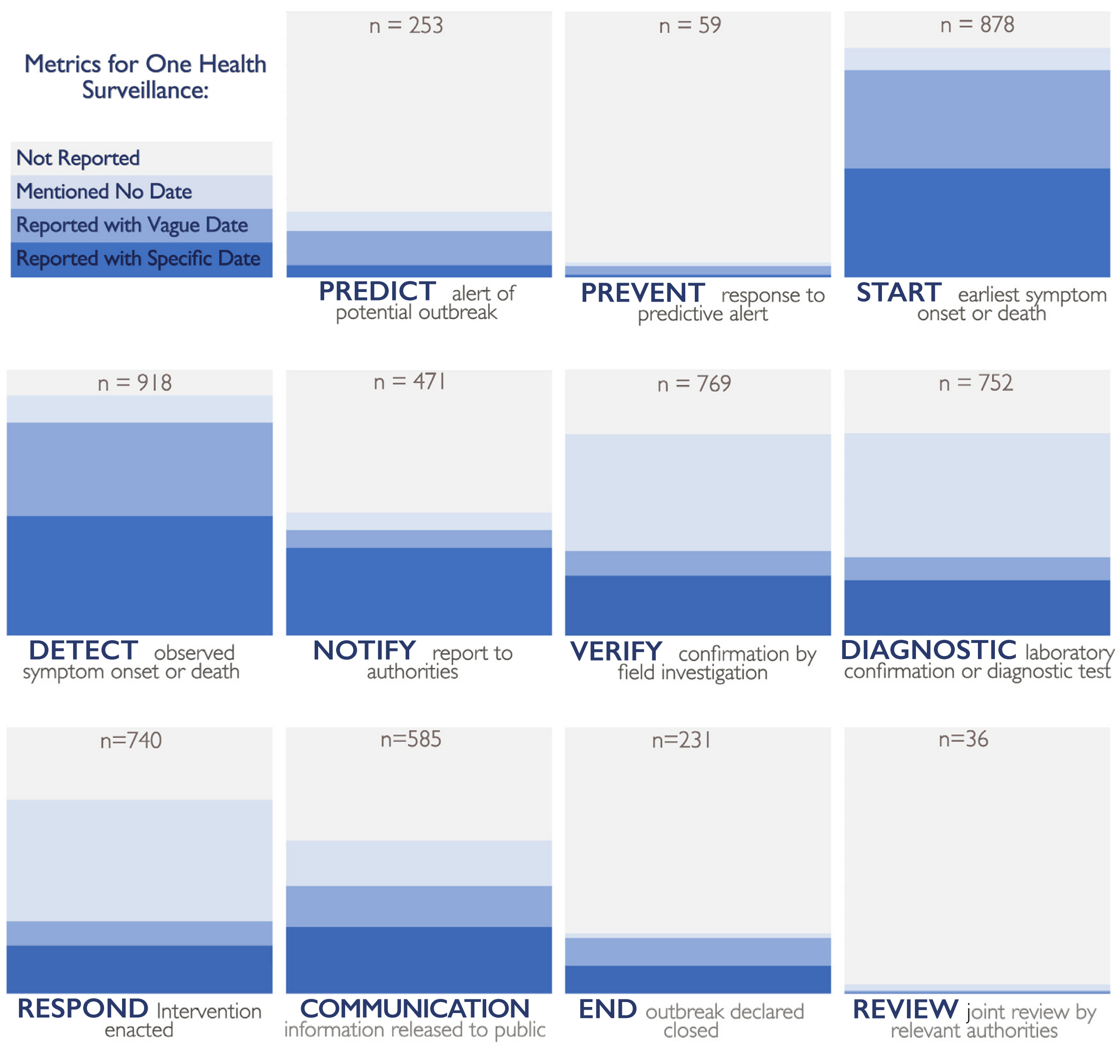

Figure 3. Stacked bar chart of milestones reported in the outbreak reports included in the scoping review analysis where *n*= milestones reported with either a specific date, vague date, or a mentioned but with no date. Each square represents 100% of the 1014 reports, for which the stacked bar chart is proportional to the frequency of the reported milestones.

Start (38·4%, *n*=390), for which the median time between milestones was zero days, followed by *Detect* and *Notify* (23·6%, *n*=239), for which the median time was 12 days. For the 96 (9·5%) reports which included both a specific *Outbreak Start* and *Outbreak End* date, the median time between the milestones was 43·5 days. Other timeliness metrics of note included the time between *Detect* and *Respond* (16 days; 10·4%, *n*=105), between *Start* and *Notify* (14 days; 20·6%, *n*=209), *Start* and *Communication* (22 days; 9·1%, *n*=92), and *Notify* and *Diagnostic* (-1 day; 13·2%, *n*=134) (Figure 4).

Though not defined as an outbreak milestone, we additionally calculated the years between an outbreak start and year the report was disseminated or published. For the 654 organizational reports with a vague or specific start date, report dissemination occurred between zero to six years after the start year, with a median time of zero years. The 130 reports in peer-reviewed journals that provided an outbreak start year were published between 0-11 years after the outbreak start with a median of two years between start year and publication year.

Discussion

Despite consensus among stakeholders on the need to improve outbreak response, observed gaps in milestone reporting suggest the need for more universal agreement on outbreak reporting, including the definitions of milestones, such that robust tracking of critical time points in outbreak detection and response can occur and the efficiency of responses be compared. That said,

Milestone	Predict	Prevent	Start	Detect	Notify	Verify	Diagnostic	Respond	Communication	End	Review
Predict		3 (0-9) n=3	18 (0-116) n=32	18 (2-278) n=35	27.5 (4-117) n=24	42 (3-117) n=15	30 (4-117) n=15	20 (2-85) n=13	15.5 (0-117) n=12	44 (27-82) n=5	n=0
Prevent			5 (1-109) n=8	6 (1-109) n=8	10 (3-109) n=4	3 (2-106) n=4	3 (2-17) n=3	5 (0-267) n=7	1.5 (0-3) n=2	38 n=1	n=0
Start				0 (0-47) n=390	14 (0-481) n=209	11 (0-242) n=167	13 (0-231) n=155	20 (0-304) n=99	22 (-40-299) n=92	43.5 (0-1010) n=96	55.5 (17-94) n=2
Detect					12 (0- 481) n=239	10 (0-242) n=175	10 (0-242) n=168	16 (0-304) n=105	21 (-40-287) n=93	41 (-33-1010) n=91	55.5 (17-94) n=2
Notify						0 (-131-42) n=150	-1 (-131-35) n=134	3 (-79-75) n=95	3 (-70-235) n=75	15 (-22-912) n=63	39 (34-44) n=2
Verify							0 (-70-63) n=147	0 (-25-64) n=74	1 (-42-34) n=64	23.5 (-9-908) n=40	30.5 (17-44) n=2
Diagnostic								1 (-63-205) n=56	1 (-15-201) n=50	26.5(-33-900) n=42	(n=0)
Respond									0 (-30 – 68) n=85	20.5(-264-425) n=34	10 (0-20) n=2
Communication										14 (-7-899) n = 27	10 (0-20) n=2
End											18 n=1
Review											

Figure 4. Timeliness metrics, defined as the median time in days between two outbreak milestones, where *n* = number of outbreak reports reporting specific date of both milestones. Range of dates in parentheses. Milestones have been organized in sequential order, from left to right, recognizing that several milestones between *Detect* and *Communication* may not always occur in the exact order of events.

we recognize that it may not be possible to delineate each milestone for all outbreaks, since reports are generated at various stages of an outbreak's progression. Furthermore, there are several inherent nuances, given the nature of organizational reports and peer-reviewed publications, which may determine which and how milestones are reported. For example, organizations and agencies are more likely to report on early investigations of suspect outbreaks, which may then be discontinued due to lack of follow-up or as outbreaks resolve on their own. Similarly, our evidence suggests that outbreaks are less likely to be written up and published in the peer-reviewed literature if the aetiology of the causative agent is not established, which would explain our observation that nearly all (95·2%, 139 out of 146) of reports in peer-reviewed journals described the *Diagnostic* milestone, compared to 73·8% (641 out of 868) of organizational reports. With an additional two years in median time to dissemination, we would also expect to see specific *Outbreak End* milestone dates described more often in reports in peer-reviewed journals than organizational or agency outlets that are most often prepared and conveyed in real-time. In fact, we found that 62·0% of the peer-reviewed reports (90 out of 146) provided or at a minimum mentioned an *Outbreak End* date compared to 16·4% of the organizational reports (142 out of 868) (Supplemental Table 3). Our finding that only a quarter of all reports specified the conclusion of the outbreak leads us to recommend that reports explicitly state the date the outbreak was declared over. If the outbreak has not yet ended, we recommend reports explicitly state the outbreak is ongoing. Without specification about the conclusion of the outbreak, we cannot track or assess outbreak response improvements over time.

In addition to *Outbreak End*, we believe that several milestones, in particular, should be reported without fail with a specific date whenever possible, including the *Outbreak Start, Detect, Notify, Respond, and Communicate* milestones. Dates for these milestones should be reported as specifically as possible (i.e., a day within a month of a year), as the frequency of the reporting we found suggests these milestones occur across the majority of outbreaks and are feasible to capture. The median time between *Notify* and *Diagnostic* milestones, which was -1 day, illustrates how formal notification to authorities may often occur only after diagnostic or laboratory confirmation of aetiology. Waiting for diagnostic confirmation may cause a response delay, which may grow problematic if it further affects mobilization of public health resources. This finding suggests that responders and investigators may be reluctant to signal any unnecessary alarm to authorities until the pathogen is confirmed. In the case of emerging pathogens, this desire to confirm aetiology prior to raising a warning can be deadly, as seen in the COVID-19 pandemic.

By restricting this analysis to English language publications, we realize there are outbreak reports, including those generated at the ministerial level, which were not captured in this analysis. However, we did use platforms, such as ProMED and the WHO's DONs, which are third-party aggregators that summarize outbreak information from a variety of sources, including non-English reports. While we did not try to capture every outbreak in every country, we recognize that country-specific considerations, such as varying reporting thresholds or cultural contexts, may affect reporting bias.

At a country level, timeliness metrics can help guide governments in setting their own targets or highlight where efforts must be directed to achieve goals such as the "7-1-7" targets described by Dr. Tom Frieden,[21,22] to identify new suspect outbreaks within seven days of outbreak start, report on and initiate investigation within one day of identification, then implement an effective response within seven additional days. Based on the observed timeliness metrics from our study, however, it is conceivable that the seven-day target between reporting or initiating an investigation and the effective response might be best set even shorter (i.e., a targeting a median time of 3 days between *Notify* and *Respond* and targeting a median time of 0 days between *Verify* and *Respond* may be feasible during outbreaks).

The interdependence of the *Predict* and *Prevent* milestones, whereby a predictive alert prompts a preventive response, may explain the less frequent reporting of the *Prevent* milestone; it is conceivable or even likely that outbreaks may have been averted following a preventive response therefore never written up for dissemination.

In a comparison of timeliness metrics for those reports providing a specific date for both the *Predict* and *Prevent* milestones (*n*=3) versus those reports providing a *Predict* date but no *Prevent* date (*n*=42) or neither a *Predict* nor *Prevent* date (n = 761), we found the median time in days to most milestones was on average shorter for outbreaks reporting a *Prevent* milestone (Supplemental Tables 4−6). One such example was a 2012 PLoS ONE publication by Dechet et al. describing a 2005 leptospirosis outbreak in Guyana following particularly heavy rainfall.[23] In response to major flooding, the government of Guyana requested assistance from the U.S. CDC on January 24th to increase surveillance for waterborne diseases. Several days later, on January 29th, investigators detected symptoms in a previously healthy individual, with the first laboratory confirmation of leptospirosis occurring on February 1st. One day later, on February 2nd, Guyana began a massive chemoprophylaxis campaign to individuals exposed to flood waters.

In this example, the time in days between the *Outbreak Start* and *Respond* milestones was 4 days, (a median of 2·5 days for both [*n*=2] reports in the study that provided specific *Predict* and *Prevent* milestone dates) compared with 22·5 days for reports with only a *Predict* milestone mentioned (*n* = 4) and 22 days for those reports with no *Predict* milestone mentioned (*n* = 73). Though the small sample size is a limitation, we believe the comparatively shortened median times between most milestones is a compelling argument for increased attention to these two milestones, both of which were relatively inconsistently reported at the time of this analysis. Efforts to identify and respond to predictive alerts will necessitate a One Health approach across fields, as well as an emphasis on event-based surveillance. By shifting away from a passive 'wait-and-see before responding' approach and toward a more vigilant alert and response system, countries may be better able and more likely to pick up signals of outbreaks, allowing for more rapid control of outbreaks at their source. Even if investigators over-alert on potential outbreaks then find that a scaled-back response or no response is needed, fewer outbreaks that could potentially grow to be protracted epidemics or pandemics will slip through the cracks, thereby averting cases and socioeconomic disruptions.

A few studies, including Chan et al. (2010), Kluberg et al. (2016), and Impouma et al. (2020), have begun to use timeliness metrics to assess how the time to different outbreak milestones have changed over time.[24−26] These analyses have focused on outbreaks occurring among humans, rather than multisectoral One Health outbreaks which are increasingly more often the case in emerging infectious diseases and diseases with pandemic potential.[27] In addition, previous studies have used slightly different milestone definitions from the eleven we tracked because there has yet to be a concerted effort to standardize outbreak reporting. Before timeliness metrics can be meaningfully utilized and interpreted across different contexts and settings, definitions of milestones must be universally agreed upon and implemented. For example, the Impouma et al.[24] study, which adapted milestones defined by Chan et al.,[25] considered date of notification as the date the outbreak event was first reported to the WHO. Our definition of *Notify* was broader, to include any notification from local to national authorities, notification across relevant sectors, or notification to international authorities. If definitions are to be standardized to allow for cross-country comparisons, we must consider the trade-off that narrow milestone definitions may prohibit stakeholders from capturing these dates altogether, given the differing realities and contexts in which outbreaks occur. Given the findings of this scoping review, particularly those findings related to the *Predict* and *Prevent* events, we believe milestones should be a feasible, flexible, and useful tool for multiple One Health sectors and thus should include a broader set of key outbreak activities in order to be most useful.

This study additionally provided an opportunity to better understand the landscape of outbreak reports across different platforms. Of note, we identified seven peer-reviewed journal reports which were authored by external, international authors with no representation of authors from the country in which the outbreak took place. This absence of local co-authorship is a reminder of the power dynamics that need to be redressed in global health research as we work to decolonize and democratize the field and practice.[28] Through programs that engage future global health workforces, such as the Field Epidemiology Training Program or the USAID One Health Workforce-Next Generation project, we believe that further socialization of these One Health milestones and timeliness metrics, along with accompanying skills related to analysis, writing, and leadership, may contribute to efforts to address this gap. Indeed, when the Salzburg Global Seminar session was convened in 2019 to establish the One Health timeliness metrics, the 38 contributing participants represented organizations across 17 countries worldwide of varying economic strengths.

The COVID-19 pandemic has also demonstrated the utility of timeliness metrics in comparing disease detection and public health response times among reporting units. For instance, California (USA) confirmed the state's first COVID-19 case in Orange County on January 25, 2020, 32 days before the county's Health Officer declared a Local Health Emergency and 39 days before the Governor of California declared a State of Emergency for the entire state.[29,30] San Francisco was the first county in California to respond to the pandemic, even before the first local case was detected; Mayor London Breed declared a State of Emergency on February 25, nine days before the Department of Public Health announced the county's first confirmed cases on March 5.[31] Additionally, in a comparison of all timeliness metrics calculated from the scoping review versus just the COVID-19 reports included in the review, the median time in days was shorter between *Diagnostic* and *Respond* milestones for COVID-19 (-1 day, n= 3 reports) compared to other One Health outbreaks (1 day, n=53 reports). Though a response occurred on average before diagnostic confirmation during the COVID-19 pandemic, timeliness metrics were comparatively longer between all other milestones, including a median time of 19 days between *Detect* and *Notify* for COVID-19 compared to 15 days across other One Health outbreak reports. Despite the small sample size, these metrics illustrate that early reporting of both predictive alerts and of detected outbreaks contribute to faster response and more optimal outcomes. If we consider the December 30th ProMED alert[32] as the predictive alert of the pandemic, 57 days passed between the *Predict* and *Prevent* milestones in San Francisco, California. Such timelines need to be shortened in order to protect populations from protracted lockdowns and other severe interventions that occur once a severe disease has been able to spread.

Of note, while the *After-Action Review* milestone is ostensibly not yet being described in outbreak reports, we believe this a motivational milestone that, if adopted, would serve to remind stakeholders to engage in cross-sectoral discussions with professionals from diverse disciplines to collectively learn from and better understand the evolution and timeliness of an outbreak investigation, and prepare for the next investigation and response, if necessary. Institutions such as the WHO, the World Organisation for Animal Health, and the Food and Agriculture Organization are already advocating the practice of *After Action Reviews,* with guidelines and manuals for *After Action Reviews* as an essential practice to learn from and improve responses during emergencies.[33−35] Training curricula for future public health leaders provide the opportunity to further promote this motivational milestone.

Discussions on preventing the next pandemic are fully underway.[36−39] Despite complex politics surrounding COVID-19, the pandemic has provided policymakers a window of opportunity to invest in and strengthen all aspects of epidemic preparedness and response, recognizing the importance of a multisectoral One Health approach.[8] We recommend the adoption of universal outbreak milestones and definitions, such that baseline metrics on outbreak timeliness performance can be uniformly measured and objectively evaluated. More specifically, we recommend increased attention to and reporting of predictive alerts and preventive action in response to these alerts to maximize efforts to shorten timeliness metrics, including time to the end of an outbreak, thus reducing cases of disease. Furthermore, we believe that early communication to the public during an outbreak facilitates community support and personal action during an outbreak, contributing to optimal health and societal outcomes for all.

Our recommendations for the adoption of these milestones and timeliness metrics echoes the conclusions of other authors that have previously analysed timeliness during outbreaks. Impouma et al. recommended the use of metrics to monitor timeliness, concluding that momentum for this effort should be supported to ensure systematic tracking of milestones to continually monitor and assess outbreak response performance.[24] Routine and consistent reporting of milestones in outbreak reports published across agencies, organizations, and peer-reviewed journals may decrease the need to triangulate dates across reports and source types, allowing stakeholders to more readily quantify and objectively assess timeliness metrics. Furthermore, given the frequency of outbreaks occurring at the human, animal, plant, and environmental interface, we believe outbreak timeliness metrics should be One Health in nature, ultimately facilitating collaborations and information sharing across disciplines and sectors at the local, national, and regional levels with the long-term objective of improving and speeding up outbreak response in the future.

Contributors

The authors confirm contribution to the paper as follows: study conception and design: JAKM, JKF, NR; funding: JAKM, WS; data collection: JKF, NR;

verification of underlying data: JKF, NR, JAKM; analysis and interpretation of results: JKF, JAKM, NR; visualizations: JKF, NR, JAKM; software: NR, JKF; original draft manuscript preparation: JKF; review and editing of manuscript: JAKM, NR, EF, BB, WS. All authors had full access to all data in the study and had final responsibility for the decision to submit for publication.

Data sharing statement

The dataset generated and analyzed in the study is available from the corresponding authors, JKF or JAKM, upon request.

Declaration of interests

The authors have no potential conflicts of interest to declare.

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Supplementary materials

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