A Novel Approach to Zoonotic Population Health Monitoring: The Zoonoses Integration Project

Introduction

Zoonotic diseases comprise most of the pathogens that currently cause human disease (Gubernot et. al., 2008) and are potential bioterrorism (Rabinowitz et. al., 2006) and emerging infectious disease agents (Ryan, 2008). Public health officials from various countries report outbreaks of significance to the World Health Organization. Delays of various lengths can occur between initial diagnosis and reporting to the local public health system, between reporting from the local to the national public health systems, and finally, depending upon the channel used for dissemination, between the public health systems and the field practitioners (Jajosky and Groseclose, 2004). In addition, zoonotic diseases are more complex than human-to-human transmission because several different animals can be involved in linking agents to cases of human disease. Animal reservoirs, including domestic, companion, and wildlife species (Scotch et. al., 2009); vectors from across the animal kingdom; and different types of hosts (primary, secondary, intermediate, paratenic, amplifying, and dead-end) create a multifaceted epidemiology. All of these species can vary in range and population due to environmental factors resulting from weather and geological events, direct human interactions, and habitat modifications (Zinstag et. al., 2009).

The Zoonoses Integration Project (ZIP) was designed to be a ‘fusion cell’ component that assimilated public health studies and reports, general media sources, and other information sources to generate a daily situational awareness (SA) report. This report had a distribution list which included the Centers for Disease Control and

Prevention (CDC), other Department of Health and Human Services constituents, the Departments of Homeland Security and Defense, and state/local public health departments. The fusion cell provided SA of current and emerging public health threats and events to give early warning and to provide real-time updates to support decision-making for public health action. Quantitative and qualitative data from disparate sources were gathered, analyzed, and amassed by subject matter experts (SME) in infectious disease, epidemiology, informatics, geographical information systems (GIS), environmental health, and veterinary medicine. ZIP was to be part of a national biosurveillance strategy for providing timely, high-quality animal, human, and environmental health information for early detection, analysis, forecasting, and research.

This paper describes the need for and the development of a multidisciplinary approach to SA that incorporates a novel approach to monitoring and reporting zoonotic disease outbreaks. Many public health administrators do not have the time nor the expertise to assimilate information from available sources to provide the SA they require on a daily basis. Moreover, health events in other countries can rapidly become global public health concerns as seen during the outbreaks associated with the Severe Acute Respiratory Syndrome coronavirus, avian (Graham, et. al., 2008) and swine influenza viruses, and filoviruses (Ebola and Marburg viruses) (Childs, et. al., 2007). A zoonotic surveillance unit that provided real-time SA could ensure timely reporting of these international public health threats. The element would monitor, analyze, and report critical outbreaks through generation of a concise daily report for international, national, district, and local SA. Seminal work on a functioning ZIP application is described in order to present ideas for use in creating a zoonoses-based surveillance system that, ideally, would be an additional component of a complete biosurveillance fusion cell (Shears, 2000).

Methods

A biosurveillance program called BioPHusion operated for two years at the CDC. ZIP was designed to merge zoonoses-specific data into the BioPHusion operational system. The ZIP computer application was interfaced directly with the BioPHusion database in order to obtain direct feeds of information from various public health sources and to allow for reverse exchange of zoonoses-specific analyses. Exclusive fields were generated for zoonotic disease, pathogen, species, and place within the ZIP application.

Research using open-source data such as ProMed and HealthMap was conducted over a two-month period. The research was conducted within the National Center of Zoonotic, Vector-borne, and Enteric Diseases at the CDC in Atlanta, Georgia. The data that were analyzed during the day were inputted into Tier 1 level records for further discussion at the daily 1:00 p.m. SA Tier 2 meetings. During these meetings, there were SMEs from various fields of expertise such as health policy, human medicine, veterinary medicine, public health, geography and demographics, and statistics. At times, additional research, analysis, or interagency communications were necessary to clarify the reliability, validity, and significance of the event being considered for the report.

The ZIP was a secure database that provided a Google interactive map with active events delineated with balloons which would provide the information placed within the 'title' text field. Links were available for both HealthMap and the Wildlife Disease Information Node (WDIN). From the 'Overview', one could navigate to 'Tier 1', 'Tier

2', and 'Data Feeds'. Navigation was also possible by selecting 'Pathogen Type' (Viral or Bacterial), 'Disease', 'Pathogen', 'Country', or 'Animal Species'.

Once within the Tier 1 page, further navigation buttons were available for 'Search', 'Add', 'Active RSS', 'Active (not on RSS)', 'Retired', and 'Unassigned'. Active events were listed in order of creation with 'Title', 'Status', 'Created' (date/time), and 'Modified' (date/time) columns. Accessible options for each row included 'Edit', 'Post', 'Recall', 'Retire', and 'View'. The Tier 2 page was similar but did not have an 'Unassigned' navigation button, 'Created' or 'Modified' columns, or a 'View' row option. Instead, there were rows for 'Initiated' (date/time), 'Last Date New Info', 'Last Analyst', 'Animals or Humans', and 'Active Linked to T1 Items'. The Data Feeds page provided links to BioPHusion, CNN Headlines, CNN Health News, EPA Emergency Response Newsfeed, Google Health News, HEDDS Surveillance News, Medworm, MSN Health Cancer, Recombinomics, WDIN New Avian Influenza Content, WDIN New Chronic Wasting Disease Content, WDIN New Content, WHO Avian Influenza, WHO Disease Outbreaks, WHO News, Wildlife Disease Information News Digest, Wildlife Disease News Digest, Yahoo Bird Flu, Yahoo Health News, and ZIP.

After navigation to the Tier 1 'Add' page, numerous text fields, text areas, radio buttons, and dropdowns were available for event entry. A unique ID number was generated for each item. A text field was provided for the 'Title' which would populate the Google Map and the concomitant Tier 1 column item. Two text fields followed for 'Description/Email Text', and 'Notes/Comment'. Next, a dropdown for 'Info Source' allowed selection of the data origin followed by a text field for the 'Link to Original Source if Available'.

The second section had radio buttons for ‘Disease’, ‘Pathogen’, and ‘Tier 2 Item’. First, a button had to be selected for ‘Disease Listed’, ‘Disease not Listed’, or ‘Disease not Mentioned’. A comprehensive list of zoonoses became assessable through a dropdown when ‘Disease Listed’ was enabled. A text field was provided for ‘Disease not Listed’ for direct input. Once the disease row was filled, then a pathogen could be selected with options depending on the disease choice. A dropdown with options linked to the disease selection and a text field for unlisted pathogens were provided. Tier 2 items could be assigned or left unassigned. Once a Tier 2 item was created, a dropdown would allow the linkage and population of Tier 1 information to the Tier 2 entry.

The third section had a text field for a ‘Case Count’ and radio buttons for ‘Species’. Species options included ‘Wildlife’, ‘Domestic’, ‘Companion’, ‘Zoo’, ‘Feral’, and ‘Unknown’. Another row within ‘Species’ had buttons for ‘ITIS’, ‘Not in ITIS’, and ‘Unspecified’. The ‘ITIS’ button provided a dropdown for ‘Recent Species’ and a text field for a ‘Species Search’ option from the Integrated Taxonomic Information System (ITIS). The name of the animal from the source could be entered in the text field to create search results with ‘ITIS ID’, ‘Common Name’, ‘Genus’, and ‘Species’. The appropriate selection would populate the species text field.

The final section was for ‘Place’. Radio buttons for ‘GeoNames’, ‘Not in GeoNames’, and ‘GPS Coordinates’ were available. Choosing the GeoNames alternative created the same choices as for ITIS with both ‘Recent Places’ and ‘Place Search’ options. If ‘Not in GeoNames’ was selected, then the following statement appeared: ‘Although you cannot find your place in the GeoNames table, please find the next best match so that a point will appear on the map. If necessary you can select only the country but please find the closest location if at all possible.' In addition, an 'Enter Place Description' text field became available. Finally, if entering GPS coordinates, the following statement came into view: 'Although you have GPS coordinates, please select the closest GeoNames location to facilitate Country and State/Province level reporting.' Text fields for 'Latitude (Y Coordinate)' and 'Longitude (X Coordinate)' allowed entry of GPS coordinates.

To add a Tier 2 item, a unique ID number was generated and a text field was offered for an entry title. The only dropdown was for the disease which is required to match the corresponding Tier 1 item. ZIP analysts could comment within text areas for 'Description' and 'Notes'.

Once a Tier 1 item became active, the entry could be edited with an 'Update' or 'Create Child Tier 1'. Child Tier 1 items populated all the same Tier 1 fields as the parent entry. Additional sources, diseases, species, and places could be entered and linked to the original Tier 1 entry.

Over 150 Tier 1 and 25 Tier 2 items were created to get familiarized with and to evaluate the utility of the ZIP application. Zoonotic diseases that were identified within the prior 24 hours were analyzed. If the disease met one or more of the zoonotic information requirements, it would be included in one of three sections of the report (new domestic or international outbreaks, social media-reported outbreaks, and new scientific study articles). If selected for SA reporting, BioPHusion analysts could access the ZIP entries through a link on the BioPHusion database to produce the formatted information required for the daily report. A standard operating procedure (SOP) was written to facilitate cross-referencing between ZIP and BioPHusion analysts.

Additionally, RSS feeds for ProMed and the Wildlife Disease News Digest were subscribed to for direct email notice. A ZIP information requirements document and a zoonotic disease PowerPoint was created by the preventive medicine veterinarian to assist non-veterinary analysts. Important zoonotic diseases and their synonyms were listed to help the analysts find pertinent sources. Animal-only and human-only diseases were excluded from the list. The PowerPoint provided a brief primer of bacterial, parasitic, rickettsial, viral, prion, and fungal zoonotic diseases. Slides included the causative agent, known reservoirs, synonyms, disease epidemiology, disease characteristics in animals, disease characteristics in humans, modes of transmission, prevention methods, and surveillance recommendations.

Results

Every morning, Monday through Friday, an analyst reviewed the various sources for relevant data. ProMed, HealthMap, and the Wildlife Disease News Digest were the most commonly cited sources. Recommendations were made for additional sources to be added to the 'Info Source' dropdown as needed. The disease list was alphabetical and fairly comprehensive. The pathogen list linked to the diseases did not always provide a generic option which is necessary when a media source does not provide the actual implicated strain or when the agent has not been subtyped. Initially, Tier 2 items were left unassigned until concomitant Tier 2 items were created.

In the next page section, the 'Case Count' allowed only whole numbers. Entries such as '2 herds' or 'flock' were not possible. The options for species selection were sufficient but each needed clear definitions to ensure continuity. Wildlife was defined as any non-domesticated species present in nature. Domestic animals were characterized as animals confined by man for food and/or draft (e.g., cattle, oxen, goats, sheep, camels). Companion animals were listed as those maintained as pets (e.g., dogs, cats, horses, birds, fish). The definition of zoo animals was unambiguous. Feral animals were defined as those species which were previously domesticated but were now surviving on their own (e.g., cats, cattle, horses).

The ITIS database provided most of the genus and species names needed. The GeoNames database was good for country and province/state level choices, but inconsistent for drilling down to a more defined level such as city, village/town, or district/county. Boolean operators did not function within the GeoNames search function; therefore, city and country could not be searched concurrently. Though country or state level differentiation was adequate for the ZIP overview map, further research was required to generate thematic maps with GIS. Also, the entries would be maintained in the ZIP database under the selected GeoNames options which do not represent the most accurate information available.

These Tier 1 items were posted on the RSS feeds for access by BioPHusion analysts to enter into the format required for the 1:00 p.m. SA Tier 2 meetings. Most of the Tier 1 entries were not elevated to Tier 2 items after screening and analysis of all the day’s data. However, a database of zoonotic disease information was accumulating for future access and research purposes. If chosen for Tier 2 status, the ZIP application for creating Tier 2 entries was straightforward. Once created reflecting the appropriate disease, one could simply edit the Tier 1 item to assign it to Tier 2 status. The Tier 2 item was then automatically linked and any further information could be placed within the available text areas. Most commonly, comments referring to previous outbreak information and case counts were entered from the additional research, analysis, or interagency communications that were conducted. An evaluation of public health significance and response was included to assist with decision-making. Contact information was provided to everyone on the distribution list, if needed for clarification of any questions.

Problems encountered included loss of ZIP access and application inoperability when certain symbols (< or >; common in ProMed) were cut and pasted into the email text area. An information technologist was available to quickly (<24 hours) restore ZIP access. A work-around for the symbol glitch incorporated first cut-and-pasting to a Word document, deleting all ‘<’ and ‘>’ symbols, and then re-cut-and-pasting to the Tier 1 email text area. Another difficulty was getting technical assistance for adding items to the dropdowns and to further refine the application. The contract for developing and maintaining the ZIP database had reached its endpoint and was not renewed during the study period.

Discussion

The purpose of this paper was to describe an evaluation of a novel zoonotic disease surveillance application. Using the ZIP database within the context of an existing biosurveillance system provided the best utilization of generated information. A fusion cell that incorporated SMEs in human, animal, and environmental health along with experts from the information utilization fields furnished a systemic, balanced, and detailed analysis of incoming data.

Data sources. Zoonoses sources need to include information on companion, farm, and wildlife animal disease outbreaks as well as those documenting human epidemics. ProMed was the mainstay source of this study and comprised much of the data within HealthMap. Zoonoses from all animal classes including outbreaks within reservoirs, vectors, and hosts were received in timely notices. Direct ProMed RSS feeds facilitated real-time notification of relevant information. The use of RSS feeds for the Wildlife Disease News Digest also aided the monitoring of up-to-date data on wildlife and environmental issues. Other sources provided input on recently published studies that could be integrated into the ZIP database and occasionally placed into the scientific article section of the daily SA report. Less timely sources reflecting mandatory reportable disease data and trends were reported when received.

Diseases/Pathogens. Though comprehensive, the disease list only incorporated one name for each zoonosis. The zoonoses information requirements and primer PowerPoint were helpful resources for providing multiple synonyms. Many diseases were listed as ‘Disease due to…’, ‘Infection with…’, or ‘Infestation with…’ Time was required for analysts to familiarize themselves with available disease options. Analysts needed good computer support for modification of all fields within the ZIP application. A radio button for unknown disease would be helpful when an outbreak of unidentified etiology is still under investigation but a significant number of animals are affected.

The linking of pathogens to selected diseases is an excellent way to list several subtypes of the same zoonosis (e.g., influenza, cholera). A good scientific zoonotic disease database should present the best taxonomic information gleaned from the source. Subtypes are important for recommending vaccines and predicting susceptibility and transmissibility. A nonspecific option for the pathogen should be provided for each disease as sometimes the proper diagnostics have not been undertaken or the results are still pending (e.g., rabies virus vs. European bat virus, Lagos bat virus, or Western Caucasian bat virus).

Case count/species. Case counts can express the severity of an outbreak but often aggregate data is reported (e.g., herds, flocks) and undefined case definitions are used. Recommendations would include having radio buttons for suspect, probable, and confirmed case counts and ensure the definitions are in the zoonoses information requirements for each disease. General guidelines can be used; for example, public reports of disease are suspect cases (sick or dead animals), medical investigation suspicions of disease are probable (clinical signs, provider experience), and laboratory diagnosed diseases are confirmed (local or reference laboratories). A more ideal surveillance system could incorporate regular active surveillance of laboratory data. Another idea is to add text fields for listing animal groups afflicted or in the case of zoonoses diagnosed within vectors or reservoirs, to give estimates of disease distribution.

A recommendation for the species row would be to have radio buttons for reservoir, vector, or host options. Sometimes, a potential zoonoses vector is found in a new location without any diagnosis of disease carriage. This information is critical for dissemination to provide forewarning of previously unknown zoonoses in the new areas. In this case, ‘Disease not mentioned’ can be selected and the information can be stored and reported as vector only data.

The species list can also be linked to the reservoir, vector, or host buttons such as done with the disease/pathogen link. Then only those species which are known reservoirs, vectors, or hosts would appear as dropdown options. Many sources only reported general species names such as ‘fox’ without needed details like ‘gray’ or ‘red’;

consequently, difficulties arose in selecting appropriate genus and species information. Web searches were conducted to provide species geographic distribution data to assist with species selection. A good zoonotic disease database would incorporate the ranges of common species which could be linked to the place section. An option would be necessary for showing any reported changes to species range boundaries.

Place. This is an important component of basic descriptive epidemiology. With the advent of GPS and GIS technology, more accurate databases are possible. Adding a Boolean operator capability to the search function would greatly assist with finding appropriate place names. Most sources list city/town/village information along with the country name. Also, regional names smaller than country are often given representing the public health or governance districts.

In any case, a goal of ZIP was to include GIS layers for reservoir and vector species distributions, human population distributions, and up-to-date environmental and topological factors. Layers could be overlaid to provide a scientific base for predicting zoonotic disease outbreaks. Thematic maps could be created for distribution as SA report extensions linked to active entries. Access to remote sensor data would facilitate the generation of current climatic condition and vegetative cover layers.

Multidisciplinary SA daily meetings. The zoonotic disease component of the fusion cell participated in scheduled meetings to consider the expert opinions of all the available SMEs. The overlying purpose of BioPHusion was to provide knowledge of endemic, epidemic, and bioterrorism events early enough to allow public health action. Human, animal, and environmental factors were all important when evaluating potential zoonotic disease spread. The input from as many disciplines as possible was important for assessing the reliability, validity, and public health significance of sometimes inconclusive data. The value added from fusion cells with the appropriate expertise was to ensure timely and quality data reporting to decision makers who were contemplating public health interventions.

Daily SA reports. As the final product resulting from each day's data collection, analysis, and research, the daily report supplied timely public health information to several governmental entities. The entire report was distributed equally to all on the distribution list. A suggestion would be to allow dissemination of each entry down to the appropriate level for public health action. For example, a report of West Nile virus avian infections in Commerce, Georgia, could be distributed down to the public health staff and veterinarians that work in Jackson County. This is not an easy task especially when considering the practice areas of most large animal veterinary practitioners. Many veterinarians cover several counties and may live or have an office out of the affected area. Public health offices need to be proactive and maintain lists of practitioners working within their jurisdictions. To be timely, biosurveillance data has to reach those who first, need to have a suspicion of a zoonotic disease; and then, would coordinate preventive and control measures.

This qualitative study was conducted to evaluate a novel zoonoses surveillance application. The initial task was to operationalize ZIP; and then, assess ZIP's utility when merged into a functioning biosurveillance fusion center. This study showed that a zoonotic disease section could be incorporated with human and environmental health components into a single multidisciplinary surveillance unit.

A limitation of this study was that no quantitative analysis was conducted. Also, the study would be stronger if a survey with follow-up analysis was conducted of those receiving the reports.

After using a zoonotic-only surveillance application, several items were noted that could improve any future zoonotic database. The complexity of zoonotic disease was shown and recommendations were developed for modifying the surveillance application for these factors. The needs to reflect the different populations involved (reservoir, vector, host), to create an epidemiological record useful for predicting outbreak risks (GIS utilization, etc.), and to ensure a multidisciplinary approach of analysis (human, animal, and environmental health) were brought out through this research.

More research is needed to determine the biosurveillance needs of public health decision makers. Could a daily SA report provide timely and quality information to those with "boots on the ground"? In addition, quantitative research is required to evaluate the effectiveness of public health action when a daily SA report is available. Could preventive and control measures be enacted to significantly reduce the outcome variable of human zoonotic infections as a result of this information diffusion?

References

Childs J.E., Krebs J.W., Real L.A., Gordon E.R., 2007. Animal-based national surveillance for zoonotic disease: Quality, limitations, and implications of a model system for monitoring rabies. *Preventive Veterinary Medicine* 78:246-261.

Graham J.P., Leibler J.H., Price L.B., Otte J.M., Pfeiffer D.U., Tiensin T., Silbergeld E.K., 2008. The animal-human interface and infectious disease in industrial food animal production: Rethinking biosecurity and biocontainment. *Public Health Reports* 123:282-299.

Gubernot D.M., Boyer B.L., Moses M.S., 2008. Animals as early detectors of bioevents: Veterinary tools and a framework for animal-human integrated zoonotic disease surveillance. *Public Health Reports* 123:300-315.

Jajosky R.A. and Groseclose S.L., 2004. Evaluation of reporting timeliness of public health surveillance systems for infectious diseases. *BMC Public Health* 4(29):1-9.

Rabinowitz P., Gordon Z., Chudnov, D., Wilcox M., Odofin L., Liu A., Dein J., 2006. Animals as sentinels of bioterrorism agents. *Emerging Infectious Diseases* 12(4):647-652.

Ryan C.P., 2008. Zoonoses likely to be used in bioterrorism. *Public Health Reports* 123:276-281.

Scotch M., Odofin L., Rabinowitz P., 2009. Linkages between animal and human health sentinel data. *BMC Veterinary Research* 5(15):1-9.

Shears P., 2000. Communicable disease surveillance with limited resources: The scope to link human and veterinary programmes. *Acta Tropica* 76:3-7.

Zinstag J., Schelling E., Bonfoh B., Fooks A.R., Kasymbekov J., Waltner-Toews D., Tanner M., 2009. Towards a ‘one health’ research and application tool box. *Veterinaria Italiana* 45(1):121-133.