**Title: Biosurveillance Surveillance (B.S.): a systematic review**

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I (Andrew Huff) had full access to the data and I had the final decision to submit for publication.

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Not Applicable

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**ABSTRACT**

Biosurveillance is critical for detecting, identifying, and minimizing the negative consequences of infectious disease. Biosurveillance is the process of gathering, integrating, interpreting, and communicating essential information related to all-hazards threats or disease activity affecting human, animal, or plant health to achieve early detection and warning, contribute to overall situational awareness of the health aspects of an incident, and to enable better decision-making at all levels. This study conducted a systematic review to identify all extant and defunct biosurveillance systems within the past 100 years. To date, this is the most comprehensive review of biosurveillance systems conducted and includes over 800 documented traditional and syndromic surveillance systems. The results of this study highlight that there was a large reduction in the number of biosurveillance systems from 2008 to present, and the number of syndromic systems created, versus traditional surveillance, increased after 1980.

**INTRODUCTION**

Global public health biosurveillance is critical for the identification and prevention of emerging and reemerging infectious diseases, and its usefulness in public health is demonstrated by its long history.1,2 Biosurveillance is the process of gathering, integrating, interpreting, and communicating essential information related to all-hazards threats or disease activity affecting human, animal, or plant health to achieve early detection and warning, contribute to overall situational awareness of the health aspects of an incident, and to enable better decision-making at all levels.3 Although newly created biosurveillance systems are often intended to complement or expand the biosurveillance capabilities of existing systems, current global biosurveillance capacity is not comprehensively documented or reviewed in a single place. Since these systems are not documented in a single location it is difficult to determine the impact and usefulness of new biosurveillance systems.4

Without awareness of the current global biosurveillance landscape there is risk of misallocating resources to the unnecessary duplication of biosurveillance systems, while potentially leaving gaps in biosurveillance coverage. The increased risk of infectious disease emergence, and the development of new technologies to detect infectious disease outbreaks, has lead to a new era of biosurveillance research and development.4-7 The 2005 revision of the 1969 International Health Regulations (IHRs) reflects the growing necessity for timely, accurate, and integrated biosurveillance systems and tools. The revised IHRs outline novel system requirements on sensitivity, timeliness, stability, flexibility, data quality, and reporting on the local to global level.8 In 2012, the White House released its first National Strategy for Biosurveillance and it stated that a well-integrated, national biosurveillance system was imperative for decision making at all levels.9 The 2005 IHR acknowledged that biosurveillance systems often lack cohesion within countries and across global boundaries, a factor that limits their effectiveness in detecting emerging disease threats.8 While there has been much focus on describing how biosurveillance systems should be designed and how they should function, there has not been a comprehensive study examining biosurveillance structure and use over time. A comprehensive review of all of the existing biosurveillance systems is incredibly useful to identify what types of biosurveillance systems are currently needed.

In this study, past and current biosurveillance systems were collected and categorized into the largest and most comprehensive dataset of biosurveillance systems. The data that were collected contain current biosurveillance systems, failed or discontinued systems, and biosurveillance pilot studies. The data collected also describe global biosurveillance capacity over time and can be used to identify gaps in current global public health biosurveillance system capabilities. In this study, biosurveillance system counts, ownership, and composition are analyzed over time. Lastly, the geographic density of biosurveillance systems is analyzed and gaps in biosurveillance system coverage are identified. The results of this study can guide improvements in future biosurveillance research and development.

**METHODS**

*Operational Definitions*

A major obstacle in the study of biosurveillance is the lack of consistent, accepted and widely adopted definitions for the various types of biosurveillance methods and systems currently in use.10 As biosurveillance has moved beyond governmental institutions and into the realm of organizations like hospitals, zoos, businesses, technology companies, and nonprofits, information streams have diversified to include a variety of non-traditional data streams.7 The need arises for an established biosurveillance lexicon that incorporates strict operational definitions.11,12

To facilitate our analysis, before data collection, concise operational definitions were established through a literature review (see below). These definitions were selected using a modified Delphi method and consisted of public health and infectious disease experts at EcoHealth Alliance to create comprehensive operational definitions.

*Biosurveillance System*

Biosurveillance is the process of systematically gathering, integrating, analyzing and disseminating information related to human, animal, or plant health.3,13 This definition includes both systems that continuously collect health data, and systems that were established for use in outbreaks but remain dormant until activated.

*Laboratory Based Surveillance*

Laboratory based surveillance systems are biosurveillance systems that rely on laboratory confirmation of disease presence. Examples of traditional surveillance include confirmed case-counts from hospitals, clinics, and laboratory testing reports.

*Syndromic Surveillance*

Currently, there is no consensus on what constitutes syndromic surveillance. Most uses of the term refer to data collected on health events without confirmed laboratory identification. The common goal of syndromic surveillance is to identify disease clusters earlier than with traditional methods.[[1]](#footnote-1),[[2]](#footnote-2) In this study, syndromic surveillance is defined as the systematic collection, analysis, and dissemination of a broad array of non-laboratory data.12,14,15

In this study, pre-diagnostic refers to case counts without laboratory-confirmed diagnosis. Therefore, systems that count clinical diagnoses based on symptoms and syndromes are identified as syndromic surveillance. Justification for this distinction includes the clinical overlap of disease symptoms (i.e., fever, diarrhea), low specificity of interim case definitions in outbreak settings,16 and the necessity of laboratory analysis in specifying most infectious disease agents. Other examples of syndromic surveillance include over-the-counter medication purchase trends, self-reporting, and Internet search queries.

*Data*

Systematic data collection was used to identify and catalogue local, regional, and global biosurveillance systems that previously or currently collect data on human, animal, or plant health. Biosurveillance systems were identified from the websites of prominent public health organizations (e.g., the Centers for Disease Control and Prevention, the World Health Organization) and from systematic Google, Google Scholar, and PubMED search queries based on relevant keywords (e.g., biosurveillance system, disease surveillance system), specific historic outbreaks (e.g., 2003 SARS surveillance), and location names (e.g., India biosurveillance system). An intensive literature review was conducted to uncover pilot programs and historic systems that may be poorly documented on the Internet.

*Analysis*

These initial searches were designed to cast a wide net and locate as many potential biosurveillance systems as possible. Following preliminary data collection, we reviewed each potential system to ensure that it met this study’s operational definitions of biosurveillance (see previous) and the inclusion/exclusion criteria (Table 2). Laboratory networks, alert and communication systems, epidemiological reports, and past biosurveillance efforts were all reviewed but ultimately included in the final database. We excluded capacity building programs, education or advocacy groups, informal communication forums about biosurveillance, and pilot systems that were proposed but never initialized.

Then, websites and peer-reviewed literature associated with each biosurveillance system were reviewed to determine: (1) the sector of the organization which created the system (government, nonprofit, for profit); (2) the date the system was created; (3) the date the system was terminated; (4) the geographic area surveyed (global, country, region, city); (6) the types of data collected; (7) whether the system performed active, passive, syndromic, or web activity surveillance; (9) the types of organisms monitored by the system (human, animal, plant); and, (10) specific symptoms and/or diseases under surveillance.

Government agencies and intergovernmental bodies (e.g., European Commission) were identified as the government sector. Organizations self described as nonprofit or not-for-profit, 501(c)3, registered charity, or equivalent language were considered part of the nonprofit sector, while corporations were classified as “for profit” entities. Data sources were classified according to Table 1. Data were aggregated and summarized in R (Version 3.2.2 2015).

**RESULTS**

The first round of data collection identified 980 potential biosurveillance systems. 260 systems were flagged for potential exclusion (Table 2). Of these 260 systems, 161 were excluded and 99 were included. The final database contains information on 819 biosurveillance systems. Of these, 708 surveyed humans, 181 surveyed animals, and 65 surveyed plants (Figure 1). 258 systems conducted syndromic surveillance and there was inadequate information to make an assessment as to whether 381 systems were syndromic. Government entities operated 688, non-profits 133, and for-profits intuitions 30 biosurveillance systems (Figure 2). More than one of these entity types was involved in 46 biosurveillance systems.

Data were collected on each biosurveillance system’s creation and termination date (Figure 3). Of the 819 biosurveillance systems in the database, 681 have information on both year of creation and, unless currently active, year of termination. Biosurveillance systems are active for a mean 11.5 years (median 9). Biosurveillance system creation peaked in 2006, tailing off in subsequent years. Termination of active systems increased significantly after 2000, peaking in 2013 (Figure 3). Accounting for system creation and termination, the largest concurrent number of active surveillance systems was 512, occurring in 2011.

The United States (U.S.) had the largest number of biosurveillance systems (296). However, the number of biosurveillance systems per country is not by itself a meaningful measure of surveillance effort, as the U.S. also covers a larger area and a larger population than many other countries. Plotting the number of biosurveillance systems per capita for each country better illustrates infectious disease surveillance coverage of the population than raw counts, and developed nations have more systems per capita than developing nations (Figure 7). The U.S., by comparison, has 0.05 systems per 100,000. The highest value is Tuvalu, with 70.7, though Tuvalu’s comparatively small population inflates this value. The lowest values are Vietnam (0.002), China (0.001), and Indian (0.001).

Traditional surveillance was predominant for most of the history of biosurveillance (Figure 7). Both traditional and syndromic systems were created at about the same rate, until 2000 (syndromic systems made up 39% of systems labeled as either), when syndromic systems began to outpace traditional systems. Syndromic systems overtook traditional systems in 2004, and their lead continued to grow. The number of traditional systems peaked at 129 in 2007, and fell to 95 currently active; the number of syndromic systems peaked at 133 in 2011, and fell to 124 currently active (77% of systems labeled as either).

Government-sector organizations operating alone or in collaboration with other sectors were by far the largest number of biosurveillance systems (688), followed by non-profits (133) and for-profits (30). 646 surveillance systems are (or were) operated by government-sector organizations alone; 95 by non-profit alone; 33 by both government and non-profit; 17 by for-profit alone; 8 by government and for-profit together; and 5 by organizations from all three sectors.

Most surveillance systems conduct human biosurveillance (708, 600 exclusively), followed by animals (181, 59 exclusively) and plants (65, 14 exclusively). Only 105 systems collect information both on humans and animals, and 31 collect information on all three classes of organisms.

**DISCUSSION**

Through a systematic search and review process an extensive database of local, regional, national, and global biosurveillance systems that are currently collecting infectious diseases data on humans, animals, and plants was created. Since 819 systems were documented, our database is the most comprehensive listing of biosurveillance systems available to the public.

*Creation & Termination*

Beginning in 1975, new biosurveillance systems were created at increasing rates (Figure 4) and the number of active surveillance systems grew substantially each year. This trend continued through the 1980s and 1990s, with the number of new systems created each year increased from under five in 1980 to over twenty-five in 1995, 1999–2007, and 2008–2012. This reflects increased activity in the field of biosurveillance following the invention and widespread adoption of the computers and the development of the Internet.17,18,19 These inventions radically improved the way health data were stored, analyzed, and communicated. System creation peaked in 2008, with 48 new systems introduced. This may be due to the institution of the updated International Health Regulations in 2005. These new regulations called for improvements to global biosurveillance infrastructure and reporting time to help mitigate the spread of infectious diseases.1 The significant structural improvements and funding reallocation needed to implement programs satisfying these new guidelines may have taken several years to complete for many countries. The accuracy of our time series analyses (Figures 3, 4, & 5) may be skewed by information bias as older systems, especially those that have been terminated, most likely have less documentation available.

In the time period between 2010 and 2014, the numbers of biosurveillance systems created and terminated each year varied substantially, but the net amount of systems created were higher than the time period preceding 2010 (Figure 3). Suggesting that there may have been a degree of experimentation in these years where many systems were created, but not sustained. This finding could be affected by information bias, as an Internet presence that contained creation and termination dates may have become more common for systems created after 2010.

In 2011-2014, the number of systems terminated exceeded the number of systems created, causing the overall number of active biosurveillance systems to fall for the first time (Figure 3 & 4). While this could be an artifact due to the information bias mentioned above or inherent biases in the data collection procedures, economic factors were likely to have caused the decrease in the number of biosurveillance systems. The global financial crisis in 2008 had a severe impact on the U.S. economy and consequently government spending on health care plateaued in the following years with the slowest spending growth in recent history.20 As 294 of the 819 systems (approximately 36%) surveyed were U.S. based, the downturn in government spending in the U.S. is correlated with a large drop in the number of biosurveillance systems.

One of this study’s hypotheses was that the existence of multiple biosurveillance systems would tend to improve both the overall sensitivity of biosurveillance (i.e., the likelihood of detecting and event) and the timeliness of reporting (i.e., the time between an event and its discovery and reporting). Some evidence supports this hypothesis.

Chan et al. studied the time to outbreak discovery and public communication of outbreaks using a set of outbreaks confirmed by WHO and it is interesting to note that during the study period between 1996 and 2009, a time associated with rapid growth in the number of biosurveillance systems, time to outbreak discovery declined substantially, from nearly 30 days to 13.5 days, and time to public reporting of outbreaks declined from 40 days to 19 days.21 This suggest an association between the number of biosurveillance systems and the number of systems in use. Of note, the number of non-traditional systems expanded at an especially rapid rate during this period.

Since outbreak discovery and reporting occur when the first system identifies the event, multiple systems would tend to complement one another and thus result in a correlation between the number of systems in use and the speed of detection. Barboza et al. examined the sensitivity and speed of detection of outbreaks of human and animal outbreaks of highly pathogenic H5N1 avian influenza A during March 2010 using 6 well characterized biosurveillance systems.22 Systems varied in the overall sensitivity and speed of reporting H5N1 outbreaks during this period, but the overall sensitivity and timeliness were optimized using a virtual combination of all of the systems.

*Syndromic Surveillance*

Initially developed as a tool for the detection of large-scale bioterrorism, the field of syndromic surveillance has greatly expanded in the past twenty years.12 258 of the systems in our database analyze syndromic data and Figure 7 shows a significant increase in the proportion of biosurveillance systems analyzing syndromic surveillance from 1980 to the present.

The advent, adoption, and distribution of Internet access is likely a contributing factor to the expansion of syndromic surveillance because the Internet has made it easier to collect, share, and analyze the data that are used for syndromic surveillance. Most disease surveillance systems are disease specific; 2 however, this trend could be changing as more syndromic surveillance systems focus on information communicated by people over the Internet and is stored and available for rapid analysis. Additionally, the Internet has made new types of syndromic data like social media, search query, and website access log data publicly available and of these data have made syndromic surveillance easier to implement. 5,23,24 However, the value of these data and their impact on public health has yet to be quantified and determined.

*Geographic Analysis*

The visualization of global biosurveillance distribution by country as the number of surveillance systems per capita highlights areas in which no information on biosurveillance activities was found, either due to nonexistence or the previously outlined limitations (Figure 6). These results illustrate that developed nations have more biosurveillance coverage per capita than developing nations. Since most surveillance systems are government-run or funded this distribution is likely due to wealthy governments being able to afford broader biosurveillance coverage across their population. This indicates that China has very low biosurveillance coverage per capita, despite being the emergence site of two major infectious disease outbreaks (SARS and HPAI) in the past fifteen years.25

Wealth-associated factors like reliable Internet access and cell phone usage may also contribute to higher biosurveillance coverage, particularly syndromic surveillance. Future analyses could compare biosurveillance coverage with historical outbreak and disease risk data, and other country infrastructure factors. This study’s geographic analysis of biosurveillance system coverage (Figure 6) may have been limited due to information bias. This analysis may be less representative of actual biosurveillance capacity in resource poor zones where system documentation is limited.

Furthermore, the number of surveillance systems per capita is not a perfect measure of surveillance reach. Countries with areas of high population density may cover large swaths of population within the catchment area of a smaller number of surveillance systems than a country with the same population spread more evenly across a large area. These countries would appear darker on this map, with a lower system-per-capita ratio, than a perfect measure of coverage. Countries with small populations with many multi-country surveillance systems (e.g., smaller European countries) will have a higher system-per-capita ratio than neighboring countries with larger populations, despite the same surveillance coverage. Nonetheless, this is a better measure than a flat count of surveillance systems per country, which are thrown off by countries such as the United States with a large number of regional surveillance systems covering different population centers.

*Biosurveillance Ownership*

Figures 2 and 5 illustrate that biosurveillance has historically been conducted by state and federal government agencies. From 2005 onward, the types of organizations involved in biosurveillance have diversified. The rise of syndromic surveillance methods that can harness an expansive range of unstructured data sources has likely served as catalyst to biosurveillance diversification, allowing non-profits, private entities and universities to become key stakeholders in the research and development of new biosurveillance methods using nontraditional data streams. Despite this, government agencies still remain the primary owners of biosurveillance capacity and data (Figures 2 & 5), often funding nonprofits through grants and sometimes working in partnership with private organizations to gather and collect health data of interest. These findings indicate that global biosurveillance may be limited, and public health may be jeopardized, if biosurveillance is overly controlled by governmental organizations. This is because the negative economic implications of reporting a disease outbreak may discourage government transparency and open data sharing practices.26

*One Health*

Of the 819 systems surveyed, the majority surveyed human, animal, or plant data discretely. Several systems (105) collect human and animal data, and fewer (31) collect data on all three subjects. With the recognition among scientists and policy makers of the interdependency of human, animal, and environmental health, and the growing prominence of the One Health Movement, the number of mixed-subject biosurveillance systems may increase in the future. With 60% of human infectious diseases caused by pathogens shared with wild or domestic animals, simultaneous biosurveillance of animals and humans is critical to detecting and mitigating the risk of infectious diseases.27 By publishing this database, we hope to encourage the merging of human, animal, and plant surveillance efforts to coalesce and coordinate risk mitigation efforts and identify infections at the critical point before an outbreak can reach epidemic levels.

**CONCLUSION**

Biosurveillance is not a new area of study and was first established over 600 years ago.28 While this biosurveillance database is substantial, it is not a complete or exhaustive list of biosurveillance efforts globally or throughout history. Factors that limited the completeness of our data collection include time and labor constraints, and limited accessibility of information. In some cases, detailed information on systems was protected, or required organizational clearance for access. Even when resources were publically available, sources were often incomplete and vague, lacking basic information about the system. Details about system characteristics like, data sources, dates of creation and termination, and status of activity and geographic range were not always available via literature or websites, leaving gaps in the data.

The ultimate goal of biosurveillance is extremely timely and accurate detection.29 Unfortunately, many biosurveillance systems are siloes that do not usefully share the information they collect, limiting the power and scope of policy they can inform. Public health benefits the most when biosurveillance information facilitates the accurate diagnosis of symptoms to create concise case definitions rapidly.30 Early identification of cases can result in significant economic savings and greatly reduce the number of cases.31 As public health and biosurveillance advances, open data sharing is necessary to detect rapidly spreading disease outbreaks and respond to them before they become epidemics. Enhanced international mechanisms for outbreak detection, alert, and response will be needed and data sharing may be able to help bolster outbreak detection.32 Infectious disease reports are increasingly being added to the Internet and the combination software and the Internet will make biosurveillance data sharing easier.33 As biosurveillance has, and will continue to be, an integral tool in monitoring global public health, the current state of biosurveillance needs to be monitored to avoid unnecessary duplication of systems and to ensure complete monitoring of infectious disease outbreaks geographically.

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**Tables and Figures:**

Table 1. Data source classification categories with their operational definitions and examples.

|  |  |  |
| --- | --- | --- |
| Surveillance Systems’  Data Sources | Operational Definitions | Examples |
| Clinical | Data gathered from medical facilities or professionals | Physician diagnoses, Emergency Dept. data (chief complaint, hospital admittance), veterinary services |
| Non-clinical | Human health related or syndromic data gathered or inferred from nonclinical sources | Prescriptions, OTC sales, absenteeism, call centers, health plans |
| Laboratory | Data gathered from laboratories | Laboratory test results; includes culture-dependent and culture-independent methods |
| Public health organizations | Reports from accredited public health institutions or organizations regarding human health | Incidence and prevalence reports, case counts from organizations like CDC, WHO |
| Food, plant, or animal | Reports from accredited institutions or organizations regarding animal, plant, food or environmental health and safety | FAO, animal control, plant regulatory agencies |
| Field reporting | Data collected on plant or animal health in the field | Wet market surveillance, sick or dead domestic animals and wildlife, presence of pests |
| Self reporting | Voluntary reports | Surveys, polls, case reports |
| Literature | Peer reviewed literature | Journals, books |
| News | Media sources | Online and print media |
| Social media | Social networking websites and applications | Facebook, Twitter |
| Internet activity | Patterns of internet usage | Search queries, web access logs |
| Other surveillance systems | Data gathered from other surveillance systems |  |

Table 2. The biosurveillance exclusion criteria based on each system’s characteristics.

|  |  |
| --- | --- |
| Systems Excluded from Analysis | Systems Retained for Analysis |
| * Capacity building networks * Biosurveillance education programs * Advocacy and policy groups * Informal communication forums * Pilot systems never used * Information deemed insufficient | * Software platforms * Communication platforms * Alert systems * Epidemiological reports * Pest biosurveillance |

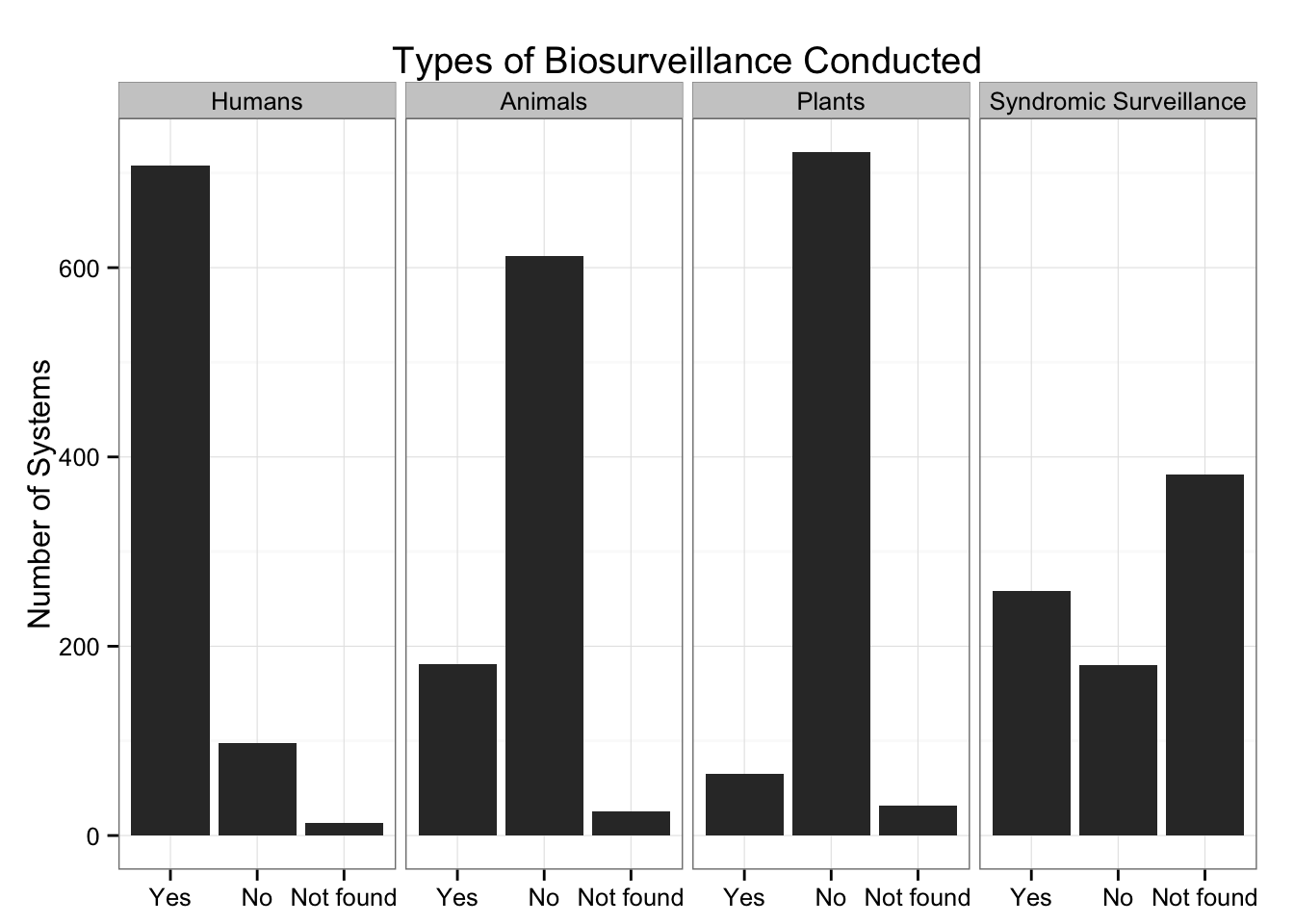


Figure 1. Populations targeted by biosurveillance systems and the number of systems within each population type. Some biosurveillance systems cover multiple species.

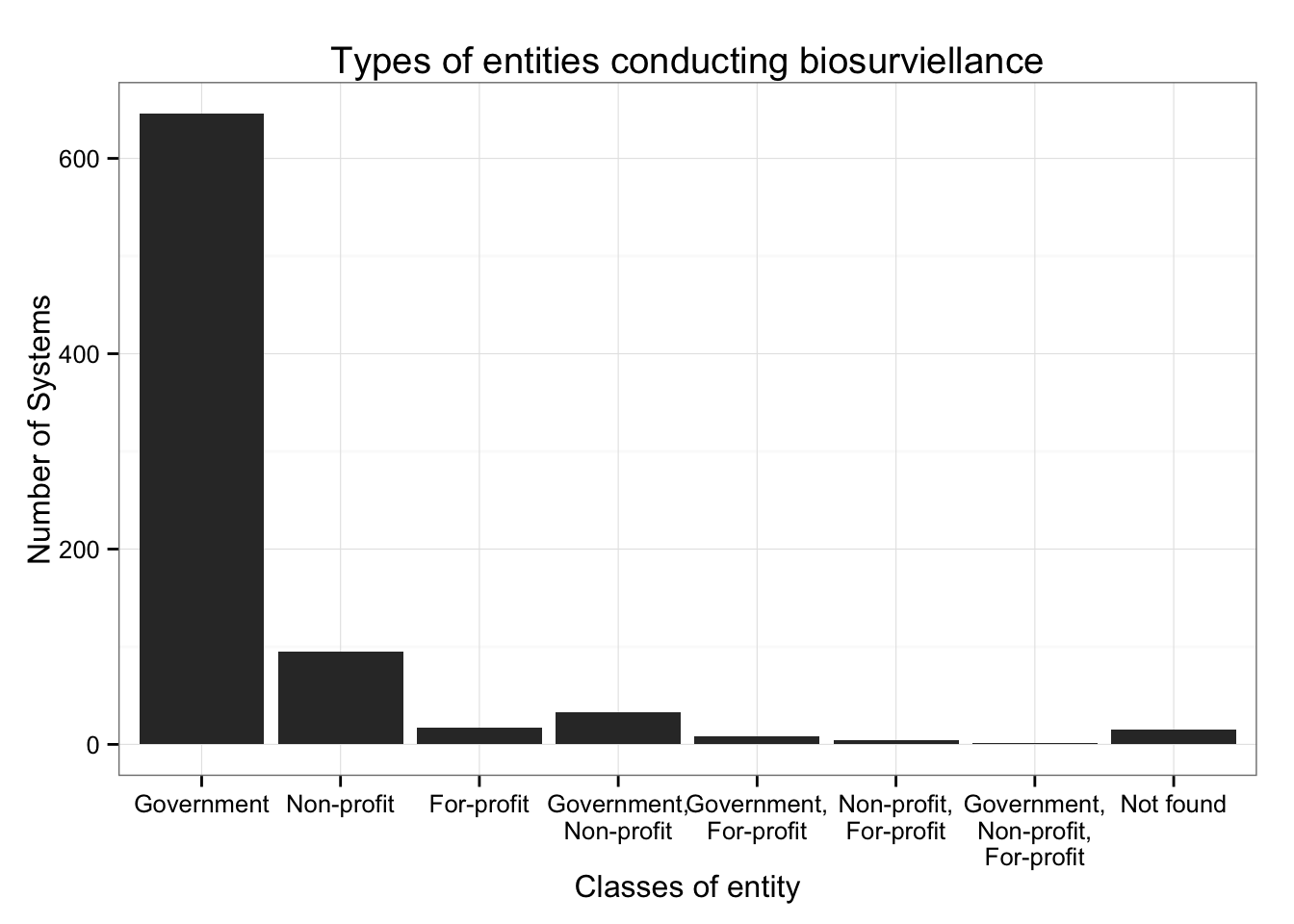


Figure 2. The ownership biosurveillance systems by ownership class.

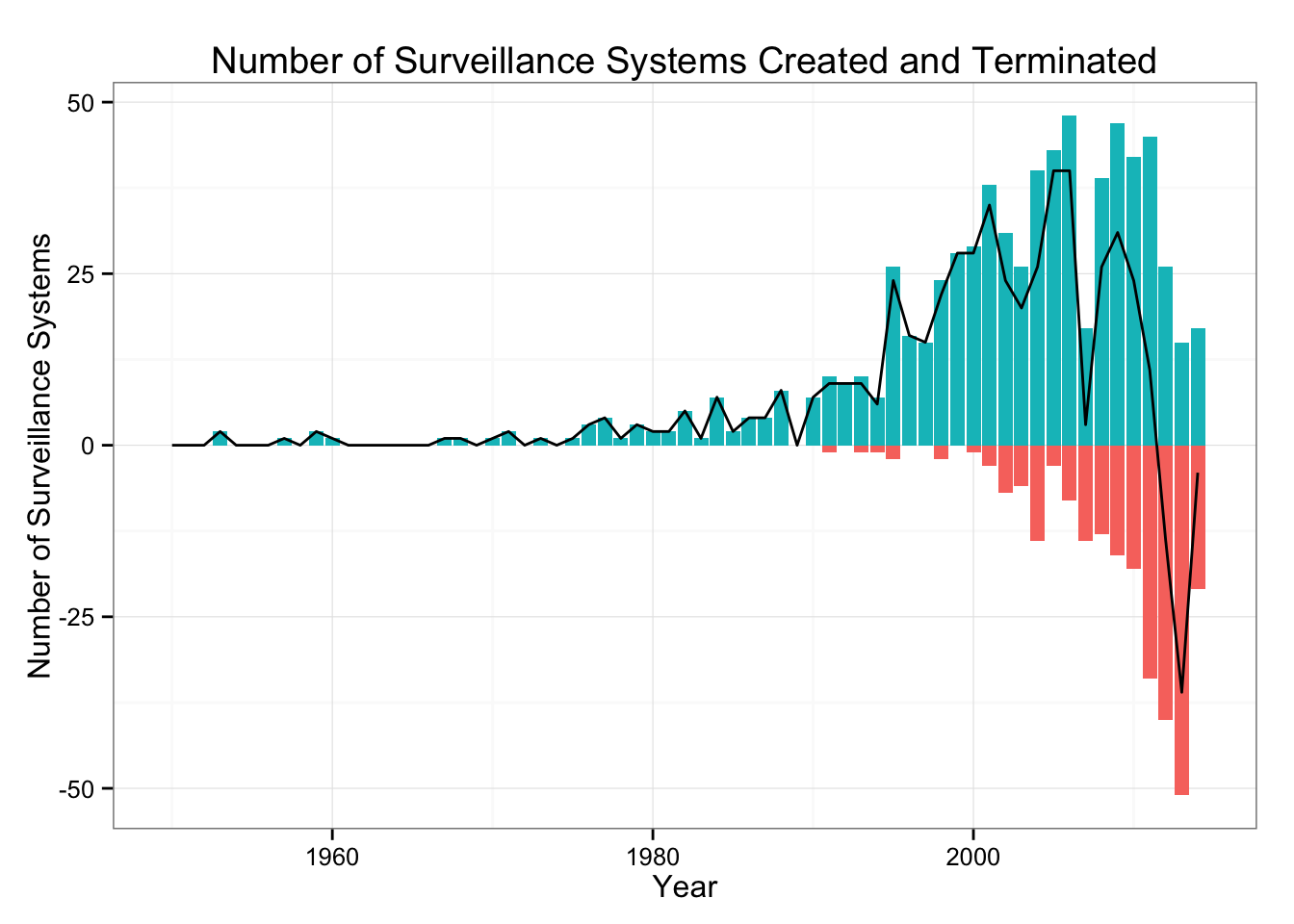


Figure 3. The number of biosurveillance systems created and terminated over time. There is a significant decrease in the amount of terminated near 2008.

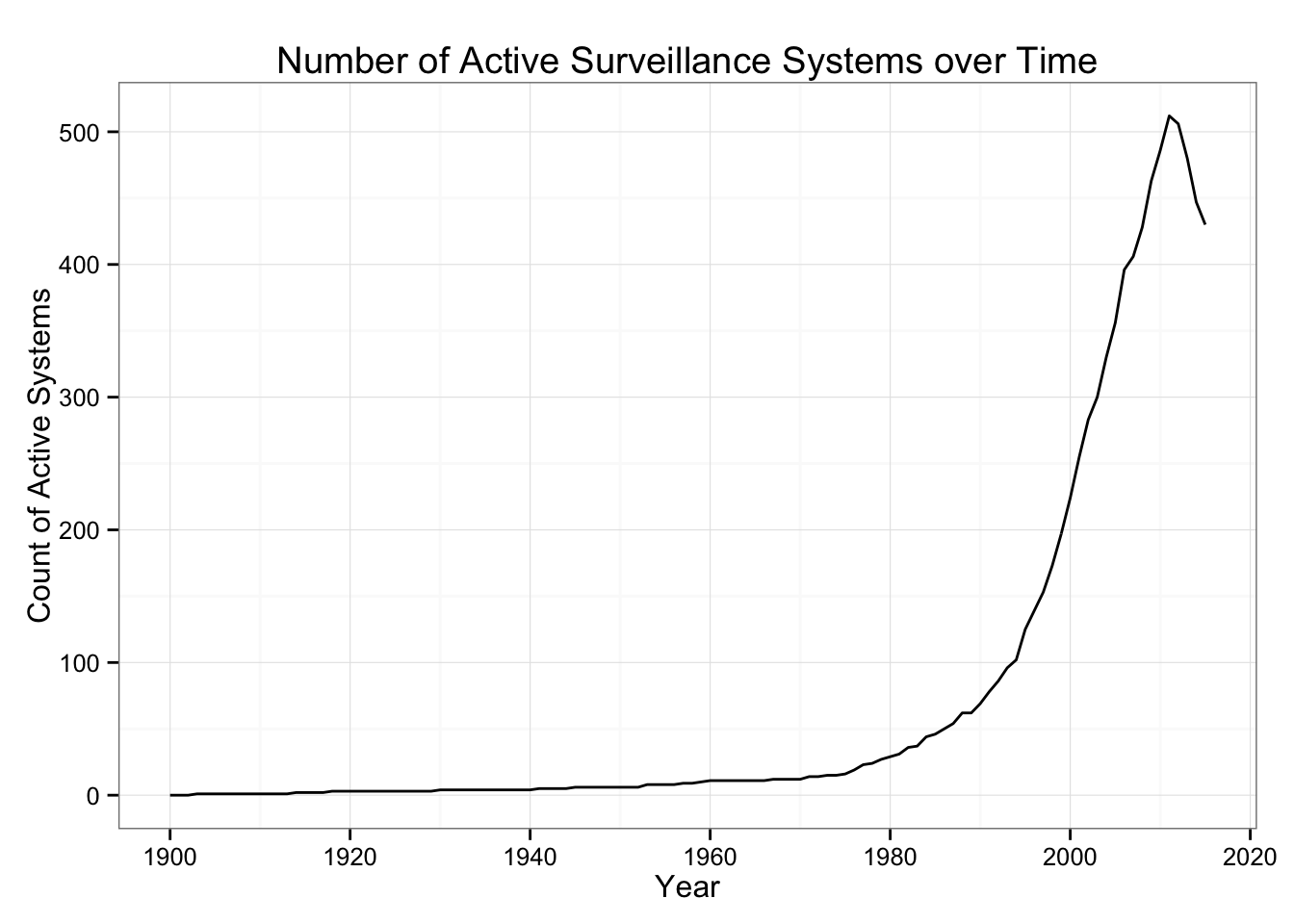


Figure 4. The number of active biosurveillance systems over time.

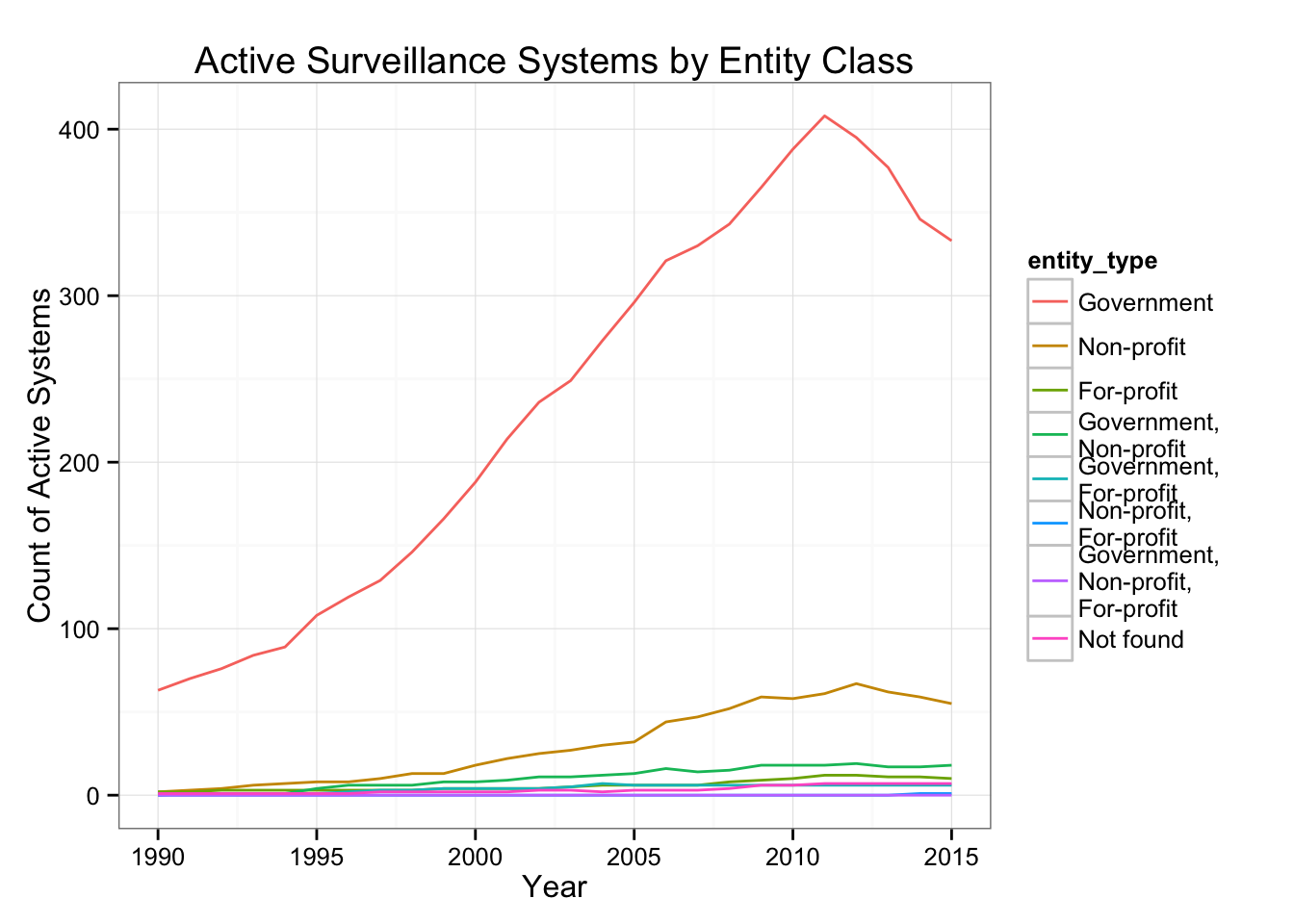


Figure 5. The amount of biosurveillance systems by entity class over time.

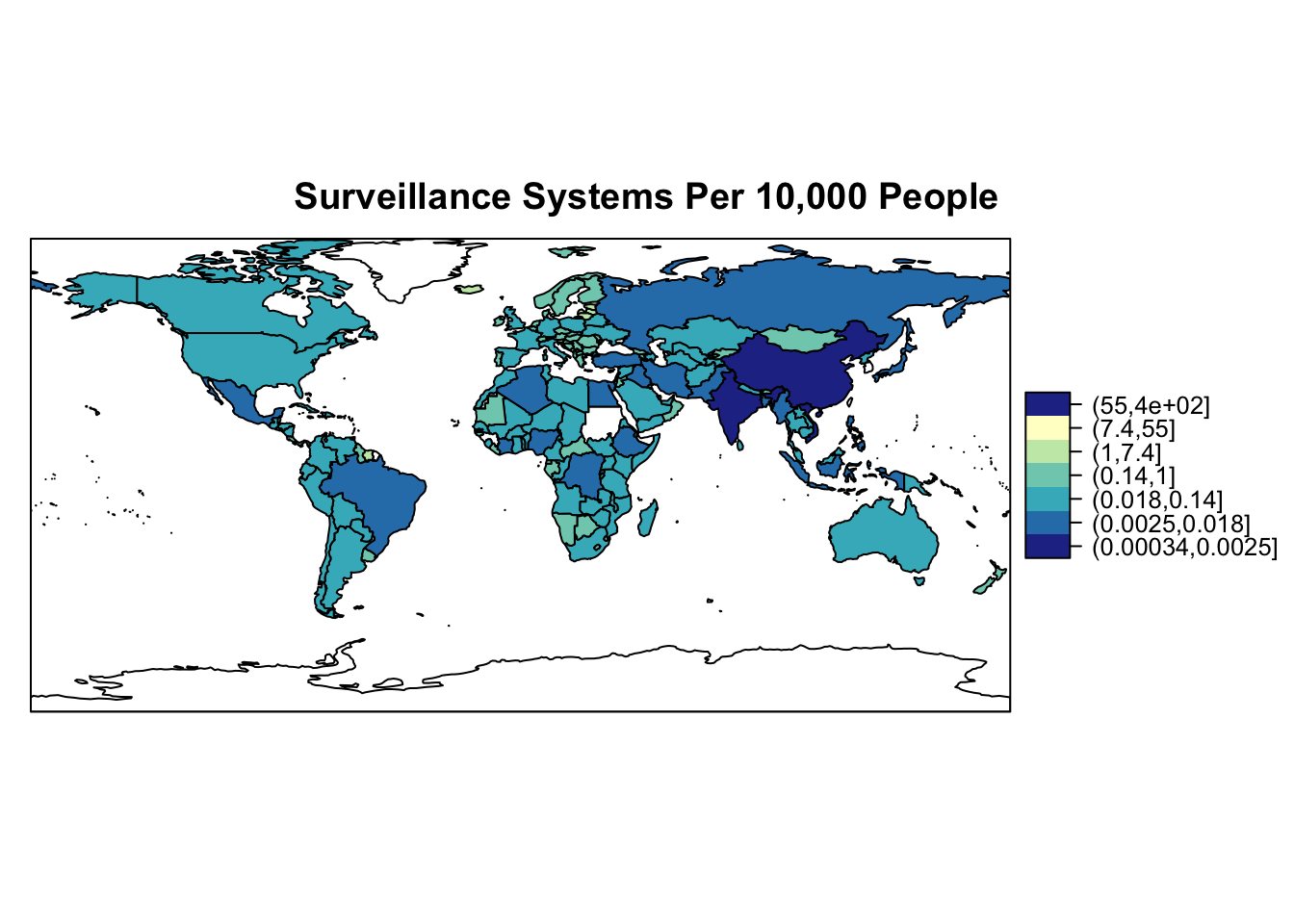


Figure 6. The spatial distribution of biosurveillance systems by country per 10,000 people.

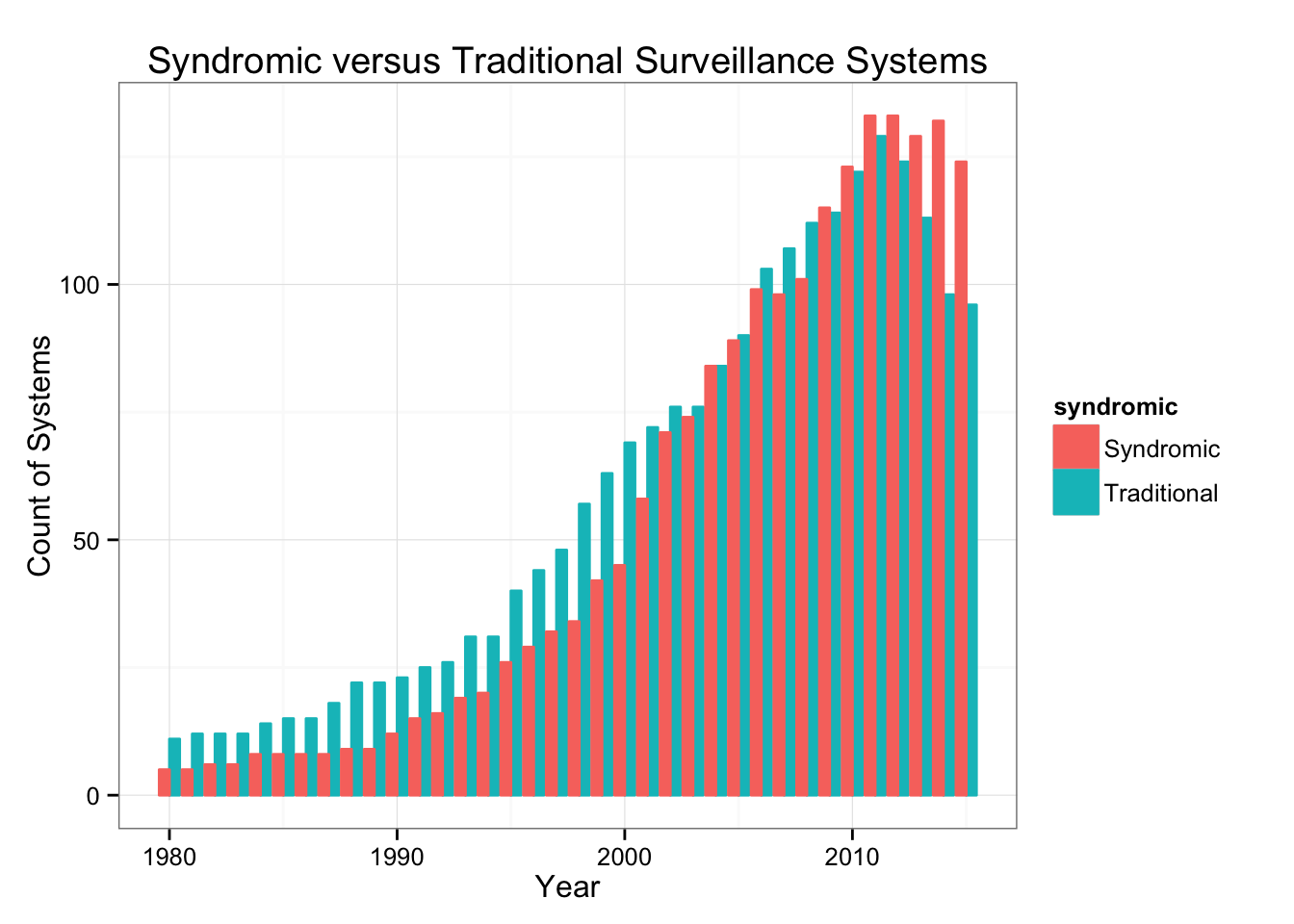


Figure 7. Increasing number and proportion of biosurveillance systems conducting syndromic surveillance versus traditional surveillance.

1. [↑](#footnote-ref-1)
2. [↑](#footnote-ref-2)