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Observed and projected drivers of emerging infectious diseases in Europe

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Emerging infectious diseases are of international concern because of the potential for, and impact of, pandemics; however, they are difficult to predict. To identify the drivers of disease emergence, we analyzed infectious disease threat events (IDTEs) detected through epidemic intelligence collected at the European Centre for Disease Prevention and Control (ECDC) between 2008 and 2013, and compared the observed results with a 2008 ECDC foresight study of projected drivers of future IDTEs in Europe. Among 10 categories of IDTEs, foodborne and waterborne IDTEs were the most common, vaccine-preventable IDTEs caused the highest number of cases, and airborne IDTEs caused the most deaths. Observed drivers for each IDTE were sorted into three main groups: globalization and environmental drivers contributed to 61% of all IDTEs, public health system drivers contributed to 21%, and social and demographic drivers to 18%. A multiple logistic regression analysis showed that four of the top five drivers for observed IDTEs were in the globalization and environment group. In the observational study, the globalization and environment group was related to all IDTE categories, but only to five of eight categories in the foresight study. Directly targeting these drivers with public health interventions may diminish the chances of IDTE occurrence from the outset.

Keywords: infectious diseases; epidemic; pandemic; threat; drivers

Introduction

The health and economic costs of pandemic emerging infectious diseases (EIDs) can be significant. For example, the financial ramifications of an influenza pandemic can range from $374 billion for a minor pandemic to $7.3 trillion for a severe pandemic with millions of deaths.[1,2] However, even without sizable mortality, the financial costs of a pandemic can amount to tens of billions of dollars when EIDs are spread internationally through air traffic.[3]

The increase in EIDs over the last five decades has highlighted the importance of understanding the underlying drivers of EIDs.[4] By recognizing and disaggregating multiple drivers, the process of emergence can be disentangled, and the drivers can then be categorized and prioritized for public health action. For example, through monitoring and surveillance of such drivers, it might be possible to anticipate and mitigate the impact of EIDs, both in public health and financial terms.[5–8] Historically, public health has intervened successfully on a number of risk factors, such as a lack of sanitation and hygiene, poor quality of drinking water, or food safety. More recently, however, many disparate drivers interact with globalization (e.g., international air traffic) and changes in the biophysical environment and global systems (e.g., climate change).[9,10] The interconnected and interdependent nature of these drivers makes it challenging to predict EIDs.[11–14]

In 2008, the European Centre for Disease Prevention and Control (ECDC) conducted a literature- and expert-based foresight study to identify environmental, socioeconomic, and technical changes that will contribute to future EIDs in Europe.[15] The study projected that the drivers of most concern would fall into three main groups: globalization and environment, social and demographic, and public health systems.[15] Since it is inherently difficult for foresight studies to account for trends in, and

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interdependencies of, multiple drivers,[16] we validated the study[17] by comparing the projected drivers for future EIDs with observed drivers of infectious disease threat events (IDTEs) that occurred in Europe between 2008 and 2013. These IDTEs were detected through epidemic intelligence activities at the ECDC to detect, verify, analyze, assess, and investigate threats to public health.[10] The comparability of observed and projected data was enhanced by using the same categories of IDTEs and the same groupings of drivers.

Identifying, disaggregating, and prioritizing drivers can enhance our understanding of the process underlying increases in EIDs and guide public health interventions. Insights from this analysis may accelerate outbreak detection and response and inform emergency control measures.[18] More importantly, these drivers can also be targeted with interventions directly to help mitigate the pandemic threat.

Methods

Infectious disease threat events

The ECDC is mandated to monitor IDTEs through epidemic intelligence or event-based surveillance, which involves active and automated Web searches from confidential and official sources, such as the Early Warning and Response System (EWRS), Program for Monitoring Emerging Diseases (Promed), Medical Information System (MediSys), and Global Public Health Intelligence Network (GPHIN), as well as individual reports from European Union (EU)/European Economic Area (EEA) member states.

We analyzed each IDTE registered through epidemic intelligence that occurred between July 1, 2008 and December 31, 2013. Information about each IDTE (morbidity, mortality, pathogen, number of countries involved) was collected from the ECDC's event-based data registry (Threat Tracking Tool, TTT) and Communicable Disease Threats Reports (CDTRs). Owing to rapid development of epidemic intelligence methodologies, inconsistencies of data collection occurred prior to 2008 and were therefore excluded from this analysis.

The inclusion criteria for an IDTE were events recorded in the TTT and CDTRs that affected the then 27 EU member states and which had ≥ 5 cases per threat. Some extraordinary threats with less than five cases were included, such as the first autochthonous cases of a vectorborne disease in a country. Events excluded were epizootics with no human cases (e.g., avian influenza in poultry, Schmallenberg virus in cattle or sheep), noninfectious cases (e.g., side effects of vaccination), and surveillance alerts with no cases (e.g., mass gatherings, including festivals and sporting events).

The IDTEs that met the inclusion criteria were divided into 10 categories: foodborne and waterborne; vectorborne and rodentborne; airborne; vaccine preventable; other zoonoses; injecting drug use (IDU) associated; influenza; healthcare associated; multidrug resistant; and sexually transmitted (Table 1).

Drivers

Epidemiological information related to the underlying drivers of these IDTEs was reviewed from a number of ECDC sources (TTT, CDTRs, rapid risk assessments of outbreaks, threat assessments of events of concern, epidemiological reports and communications, and mission reports) and from peer-reviewed publications retrieved from PubMed. The authors evaluated the quality and validity of this information on the drivers attributed to each IDTE.

On the basis of the driver groupings of the 2008 ECDC foresight study[15] and the observed data from this study,[10] 18 key drivers were identified for the observed IDTEs in Europe. When the IDTE data for 2008–2013 were analyzed, the driver category of research and development did not match any observed IDTEs and was thus excluded, leaving 17 key drivers, as discussed below and shown in Figure 1B. As discussed further below, these 17 drivers were categorized into three main groups—globalization and environment, social and demographic, and public health systems.

Globalization and environment.

Climate. Climate variability manifested through short-term changes in meteorological conditions, such as temperature, humidity, wind, and rainfall, can influence the exposure pathways of foodborne and waterborne diseases or the distribution of vectorborne diseases.[6] Climate change, manifested through long-term (anthropogenic) changes of these conditions can also have implications for infectious diseases, for example, resulting in expansion or contraction of geographical range.[19]

Natural environment. The occurrence of IDTEs is, in part, a function of natural environmental

Table 1. Total number of infectious disease threat events, cases, and deaths, from 2008 to 2013 in Europe

Categories of events	Number of IDTEs	Number of globalization and environmental drivers	Number of social and demographic drivers	Number of public health system drivers	Number of cases from IDTEs[a]	Number of deaths from IDTEs[a]
Foodborne and waterborne IDTE	48	54	7	47	26,000	80
Vectorborne and rodentborne IDTE	27	58	9	10	4748	64
Airborne IDTE[b]	10	13	4	1	531	96
Vaccine-preventable IDTE	10	10	20	5	73,658	34
Other zoonoses IDTE	7	6	7	7	3724	12
Injection drug use–associated IDTE	4	2	9	0	159	17
Influenza IDTE	4	4	2	4	97	11
Healthcare-associated IDTE	3	2	3	3	49	7
Multidrug-resistant IDTE	2	1	3	1	76	8
Sexually transmitted IDTE	1	1	2	0	11	1
Total	**116**	**151**	**66**	**78**	**109,053**	**330**

[a]The number of cases and deaths reported in the infectious disease threat event (IDTE) database reflects the disease burden recorded through epidemic intelligence for IDTEs and is not a complete assessment of the disease burden in Europe. For a complete compilation of epidemiologic data, the reader is referred to the European Centre for Disease Prevention and Control (ECDC) Annual Epidemiologic Report,[45] which provides a more accurate estimate of mortality and morbidity.
[b]Includes respiratory infections that can be transmitted through air and/or other pathways, including infections transmitted through aerosols, fomites, or direct contact.

determinants, such as land cover, vegetation, waterways, oceans, coastlines, land use, habitats, and biodiversity, on a global scale.[20] Changes in the natural environment can, for example, influence the distribution and population size of vectors, such as rodents, mosquitoes, and ticks, and of host and reservoir animals.

Human-made environment. Urbanization, the built environment, infrastructure, industry, intensive agriculture and human-made water systems, such as cooling towers, spa pools, and humidifiers, can affect the epidemiology of IDTE;[21,22] they can be incubators of infectious diseases and contribute to rapid spread in settings with high population densities.

Travel and tourism. Travel by train, airplane, ship, car, and other vehicles can enable the importation of vectors, pathogens, and infected individuals into Europe and their dispersion within Europe.[23]

Migration. Immigrants, emigrants, refugees, asylum seekers, and settlers engage in movement that takes place outside of the regulatory norms of the sending, transit, and receiving countries; they can be vulnerable to, or contribute to, the spread of infectious diseases.[24] Also, migration from rural to urban environments may contribute to spread of disease or create susceptible groups.

Global trade. The trade and transport networks for import and export of goods across national boundaries via, for example, ship, airplane, rail, and truck, and the continuing rise in volume, frequency, and range of global trade can result in the (intentional or unintentional) exportation or importation of host animals, disease vectors, or pathogens.[25,26]

Social and demographic.

Demographic. Population characteristics, such as age distribution, can be associated with greater or lesser vulnerabilities to infectious diseases.[27,28]

Social inequality. Groups that are disadvantaged because of unequal distribution of resources, including income, privilege, rights, and social power, can suffer disproportionately from infectious diseases because of differential exposure in social, work, and physical environments or differential access to health care.[27,28]

Vulnerable groups. Vulnerable groups that are not necessarily economically disadvantaged (see above),

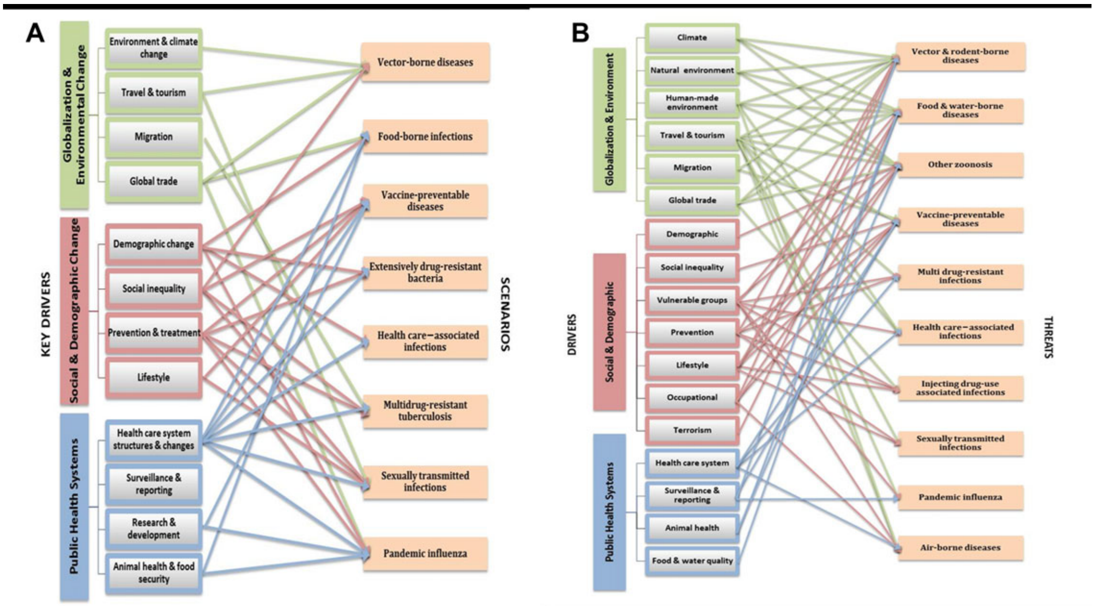

Figure 1. (A) Projected and (B) observed drivers of infectious disease threat events in Europe.

such as children, premature infants, pregnant women, the elderly, and people who are immunocompromised, can also experience increased exposure and susceptibility to infectious diseases or differential access to health care.[27,29]

Prevention. Uptake of childhood vaccination programs, adherence to prevention interventions, and appropriate prescription practices can affect susceptibility to infectious diseases; distrust of prevention interventions, such as childhood vaccination programs (vaccine hesitancy), can undermine control efforts.[30–32]

Lifestyle. High-risk behaviors, including IDU or unprotected sex with multiple partners, can increase exposure and infection rates.[33]

Occupation. Healthcare workers, veterinary personnel, butchers, farmers, and animal caretakers and cleaners can be occupationally exposed to infectious diseases. For example, inadequate infection-control practices in healthcare settings put healthcare workers at risk during the Ebola outbreak in West Africa.[34]

Terrorism. Several pathogens are marked as potential high threats if used for bioterrorism.[35] Advancements in life science research expertise have accelerated and dispersed globally, raising concerns related to dual-use applications. Methodologies for synthesizing and/or altering the virulence of pathogens in the laboratory are now readily available and thus potentially a security risk if applied with malicious intent.

Public health systems.

Heathcare system. The structure for the delivery of health services (including general practitioners, hospitals, and clinics) and access to care, medicines, diagnostics, and insurance coverage, affect health outcomes. Conversely, healthcare settings can be responsible for nosocomial infections.[36]

Animal health. Livestock practices, animal health and welfare measures, and veterinary services can influence IDTEs; for example, high animal densities can propagate infectious diseases[37] and infected animals close to human settlements can increase the risk of zoonotic epidemics.[38]

Food and water quality. Farming, food processing, handling, preparation and storage, and water treatment and distribution systems also play a role in IDTEs. Contamination of drinking and irrigation water sources and water distribution systems can lead to localized or community outbreaks.[39,40] Contamination of food along the chain from farm to fork can result in epidemics.[41]

Surveillance and reporting. Lapses in surveillance (e.g., systematic ongoing collection, collation, analysis, and dissemination of infectious disease data) can impede a rapid response to infectious disease outbreaks. In contrast, increased surveillance will contribute to increased awareness and thus result in increased reporting of cases.

Statistical analysis

Descriptive analyses were performed for each IDTE category as well as for each individual IDTE. The relationship between the different drivers and the different IDTE categories was evaluated. To assess the importance of the different drivers, the following factors were included in the analysis: (1) frequency—what drivers and driver combinations occurred most frequently in each IDTE category, (2) magnitude—what drivers and driver combinations gave rise to the highest number of cases in each IDTE category and each individual IDTE, and (3) severity—what drivers and driver combinations caused the most deaths in each IDTE category and each individual IDTE.

The influence of each driver for a certain IDTE was evaluated using multiple logistic regression models, where *i* ranges over all of the event types in different models and *j* ranges over all of the drivers within a model:

$$\mathrm{Logit}(\mathrm{Event}_i) = \sum_j \beta_j \mathrm{Driver}_j.$$

In the logistic regression analysis, the influence of a driver (j) on an IDTE type (i) was estimated according to its coefficient (β). In the later analysis, the influence was presented as a ranking of the size of positive coefficients ($\beta > 0$). The ranking of the coefficients produced comparable results over the range of j, as the values taken by the driver are consistently taking values of 0 and 1. The best models were selected according to the Akaike Information Criterion (AIC), on the basis of both model fit and model parsimony.[42] AIC was used to identify variables that contributed to the model fit and to exclude variables that did not contribute to the model according to an AIC difference criterion of at least 3, with or without the variable.

Foresight study validation

Validation of the ECDC foresight study[15] with observational data depends on the comparability of IDTE categories and driver groupings between the two studies. Such a comparison can enhance understanding of the dynamic nature of the underlying drivers of IDTEs[43,44] and their relative importance. For this study, the following slight adjustments to the IDTE categories and driver groupings were necessary to better reflect the observed data.

- The number of drivers was expanded from 12 (projected) to 18 (observed) (Fig. 1).
- The driver category of environment and climate change was expanded into three subgroups of drivers in order to better capture all of the observed drivers; these new groups were climate, natural environment, and human-made environment.
- The subgroup vulnerable groups was created, distinct from the social inequality group, to allow for more precise attribution and to reflect the fact that vulnerability is not always due to social inequality.
- The subgroup lifestyle was created, distinct from the demographic change group, to better describe the data.
- Terrorism and occupational were added as new groups.
- The driver category of animal health and food security was divided into two subgroups: animal health and food and water safety.

The IDTE categories were also partly adjusted and their number was increased from 8 to 10. Specifically, three new IDTE categories were added: other zoonoses IDTE, IDU-associated IDTE, and airborne IDTE (Fig. 1B). Furthermore, only single-case events were found in the observed data for the category multidrug-resistant tuberculosis; therefore, this category was merged with the category of extensively drug-resistant bacteria, forming the new threat category of multidrug-resistant IDTE.

Results

A total of 274 IDTEs were evaluated for the period between July 1, 2008 and December 31, 2013. Of these, 116 IDTEs met the inclusion criteria and were sorted into the 10 IDTE categories. Table 1 shows the numbers of IDTEs and of cases and deaths for each category registered by epidemic intelligence at the ECDC. In brief, IDTEs that occurred during this time period were the following:

- Forty-eight foodborne and waterborne IDTEs, which were the most common events and included pathogens transmitted through food or water, such as salmonellosis, hepatitis A, *Escherichia coli*, norovirus, and shigellosis. The number of cases and deaths in this category was substantial.

- Twenty-seven vectorborne and rodentborne IDTEs (epidemics or first autochthonous cases), including West Nile fever (WNF), malaria, dengue fever, and hantavirus, which were responsible for a large number of cases and deaths.
- Ten airborne IDTEs, including respiratory diseases acquired through airborne transmission (particles or droplets) of pathogens, such as legionellosis, and respiratory infections that can be transmitted through air and/or other pathways, including aerosols, fomites, or direct contact, such as Middle East respiratory syndrome coronavirus (MERS-CoV); the largest number of fatalities was attributed to this category.
- Ten vaccine-preventable IDTEs, including the main vaccine-preventable diseases that are normally part of public health system vaccination programs, specifically, measles, pertussis, mumps (boys), and rubella (girls); the largest number of cases was attributed to this category.
- Seven other zoonoses IDTEs, including diseases that are transmitted through contact with animals or animal discharges, such as Q fever, cow pox, and psittacosis.
- Four influenza IDTEs, including both seasonal influenza and other pandemic influenzas.
- Four IDU-associated IDTEs, which were caused by botulism, HIV, and anthrax, among other diseases.
- Three healthcare-associated IDTEs, which were infections (e.g., meningococcal meningitis) acquired while hospitalized or transmitted through healthcare practices.
- Two multidrug-resistant IDTEs, which were important emerging multidrug-resistant infections caused by carbapenemase-producing Enterobacteriaceae and *Klebsiella pneumoniae.*
- One sexually transmitted IDTE, which was responsible for serious complications, for example, meningococcal infection.

The number of drivers for each IDTE is also shown in Table 1. Of the three main groups of drivers, globalization and environment contributed to 61% of all individual IDTEs, followed by public health system drivers (21%) and social and demographic drivers (18%).

The travel and tourism category was the most frequent driver, contributing to 48 events, followed by food and water quality, natural environment, global trade, and climate. Travel and tourism contributed to nine different IDTE categories, vulnerable groups contributed to seven IDTE categories, and lifestyle to six IDTE categories.

The ranking of the contribution of the top five drivers by occurrence, number of cases, and number of deaths is shown in Table 2. Multiple regression analyses of the most frequently occurring observed IDTEs in Europe from 2008 to 2013 showed that four of the top five drivers were in the globalization and environment group: travel and tourism, natural environment, global trade, and climate. Vaccine-preventable IDTEs accounted for 68% of all cases (Table 1); therefore, the key drivers in the logistic regression for morbidity were dominated by drivers for vaccine-preventable IDTEs (Table 2). These drivers were related to the characteristics of subgroups in society that lack access to, or abstain from, vaccination. In contrast, the key drivers for deaths were heterogeneous, since the IDTEs responsible for these deaths were also very heterogeneous (Table 2). The impact of the observed IDTEs in Europe is also reflected in the number of countries affected: 42 IDTEs were multicountry outbreaks involving three or more countries, of which 10 IDTEs involved more than eight countries. Specifically, one measles event impacted as many as 17 countries.

The travel and tourism group was an underlying driver in many of the IDTEs with large numbers of cases and deaths: a vaccine-preventable IDTE caused the highest number of cases (>32,000 cases), followed by a food and waterborne IDTE with over 13,000 cases. These also include the vectorborne and rodentborne IDTE, with the highest number of cases due to the first autochthonous outbreak of dengue fever in Madeira in 2012 (>2160 cases). The travel and tourism group was also a driver for MERS, which caused the most deaths in the airborne IDTE category, and for the Shiga-like toxin-producing *E. coli* hemolytic-uremic syndrome, which caused the most deaths in the foodborne and waterborne IDTE category. The WNF event that caused the majority of deaths in the vectorborne and

Table 2. Logistic regression ranking of the top five drivers by frequency of occurrence and number of cases and deaths for IDTEs in Europe from 2008 to 2013

Ranking of drivers	Frequency of occurrence	Cases	Deaths
1	Travel and tourism	Social inequality	Natural environment
2	Food and water safety	Healthcare system	Vulnerable groups
3	Natural environment	Prevention	Climate
4	Global trade	Lifestyle	Healthcare system
5	Climate	Migration	Prevention

NOTE: Color codes are according to driver categorization: globalization and environment (green), social and demographic (red), and public health systems (yellow); see Table 1.

rodentborne IDTE category was the only high-impact event that did not identify travel and tourism as a driver but rather natural environment and climate.

Comparing the observed with the projected drivers revealed a number of differences: the most striking discrepancy was that the globalization and environment group was found to be related to all observed IDTEs categories (10 of 10; Fig. 1B), whereas it only matched to five of eight IDTEs in the foresight study (Fig. 1A). Specifically, the travel and tourism group was linked to eight of ten IDTEs in the observed data, but to only two IDTEs in the foresight study. It is important to note that travel and tourism included both pathogen importation into and exportation from Europe, as well as dispersion within Europe. The logistic regression confirmed this observation that the travel and tourism group was the most important contributor to a number of different IDTEs in Europe (Table 2). Natural environment and human-made environment were also important drivers in the observed data, but not recognized as such in the foresight study. Vulnerable groups seemed to be a more frequent driver relative to social inequality on the basis of the observed data (Fig. 1).

Discussion

Since forecasting IDTEs has proven to be hampered by a number of uncertainties,[11,14,17,43,44] we embarked on a side-by-side comparison of observed versus projected drivers. One of the striking differences was that the environment and climate change group was projected to be linked only with the vectorborne and rodentborne IDTEs in the foresight study. However, in the observed data, this group was linked to half of all of the IDTEs (the environment and climate change group was split into climate, natural environment, and human-made environment, as discussed above in the Methods section). Thus, global environmental change had been underestimated in the foresight study but was, in fact, a much more significant contributor to the observed IDTEs. This observation was also confirmed in the multiple logistic regression analysis, with globalization and environment contributing to four of the top five drivers: travel and tourism, natural environment, global trade, and climate. The contribution of globalization and environmental drivers to IDTEs might have been underestimated in the foresight study, possibly because these drivers are poorly understood and distal (or upstream) from the health outcome.[20] Globalization and environmental drivers might appear to be less amenable to direct interventions during an IDTE (e.g., travel restrictions), in contrast to social and demographic (e.g., social distancing) or public health system (e.g., stockpiling of drugs and vaccines) drivers. As a result, their contribution might have been underestimated in the expert-based foresight study. It is also possible that global environmental change has recently received more media/political attention and is now more readily recognized as a driver of IDTEs in the scientific literature.

Interventions targeting the drivers of IDTEs

The risk of EIDs has increased internationally over the last five decades, even after correcting for detection bias.[4] The financial cost of a large epidemic is staggering and can set back a country economically.[5] Thus, it is desirable to accelerate the detection of IDTEs and response capacity.[8] An even more cost-effective strategy would be to target the underlying causes of IDTEs by intervening directly on the drivers; some drivers lend themselves for direct interventions more so than others. In order to prioritize the most appropriate intervention, it is desirable to recognize the drivers responsible for a specific IDTE. Our analysis of drivers of European IDTEs sheds light on the underlying factors responsible for their occurrence. We discuss intervention options for the most significant drivers identified in our study in more detail below.

Travel and tourism

Travelers to the tropics or subtropics are at risk of dengue virus (DENV) infection.[45] Through international air travel, infected travelers can quickly arrive in Europe during their viremic period and be bitten by local *Aedes* mosquitoes.[46] These infected mosquitoes can subsequently transmit DENV locally and trigger an outbreak. In Europe, transmission of DENV has occurred in areas where *Aedes* mosquitoes are present.[47,48] For example, in 2010, two dengue cases without recent travel history or blood transfusion were identified in Southern France[47] and two other cases in Croatia.[48] Thus, for the first time in decades, local transmission had occurred in Continental Europe. In 2012, an epidemic of over 2000 dengue cases occurred in Madeira, Portugal in areas where *Aedes aegypti* is known to be present.[49]

Empirical models can be built to quantify the association between the number of monthly incoming travelers and the number of monthly dengue importations at country level; the main driver of dengue importation can then be described with high spatial and temporal resolution of international air traffic data.[23] In 2010, the dengue importation risk into areas in Europe with circulating vectors was the highest in Milan and Rome between August and October.[23] It is neither possible nor desirable to stop travel and tourism, but, by analyzing air passenger volume data, it might be possible to generate high-resolution spatial and temporal predictions for the importation risk of tropical diseases and guide seasonal surveillance activities in high-risk areas of Europe.[50]

Natural environment

The following are two examples of how the natural environment driver can be analyzed and monitored to anticipate IDTEs.[8] A number of IDTEs relate to the malaria outbreak in Greece that started in 2009 and continued until 2012.[51] The environmental suitability of transmission was mapped with nonlinear discriminant analysis, which identified warmer temperatures, low altitude, permanently irrigated land, and complex cultivation patterns as predictors.[51] On the basis of this analysis of the natural environment, other areas of Greece that are equally environmentally suitable for potential transmission were targeted for indoor residual spraying, aerial sprayings, provision of long-lasting insecticide-treated nets, active case detection, and mass drug administration; transmission was subsequently interrupted in 2013 and 2014.[52]

Waterborne IDTEs are another area of public health concern. Swimming in warm brackish water can result in infections caused by *Vibrio* species other than *Vibrio cholera,* and these infections can be serious, particularly for immunocompromised individuals. The ECDC regularly monitors the environmental suitability for such species in the Baltic through a real-time model that uses daily updated remote sensing data of sea surface temperature and salinity.[53] The ECDC Vibrio Map Viewer can trigger an early warning of high environmental suitability for *Vibrio* spp. that warrants beach closures. By monitoring such conditions in natural environments that are the natural habitat for *Vibrio* spp., such as estuaries, the geographic extent of potential human exposure can be defined and steps can be taken to protect recreational water users.

Global trade

International trade has accelerated both in terms of transit time and volume and increased the connectivity between geographically remote areas.[26] This has implications for the spread of infectious diseases; for example, contaminated food products have been shipped globally and within Europe, resulting in multistate foodborne outbreaks.[54] Furthermore, the increase in air freight has contributed to the unintentional spread of insect vectors, and the long-distance movement of used tires and ornamental plants, for example, “lucky bamboo shoots,” has resulted in the international dispersion of disease vectors, such as *Aedes albopictus*, the Asian tiger mosquito, which is a vector for dengue, chikungunya, and Zika viruses.[55] The permanent introduction of disease vectors due to freight container imports around international harbors, and further dispersion of containers by train, truck, and inland waterways, has resulted in the rapid expansion and establishment of *A. albopictus* in a several Mediterranean countries.[25] It may be possible to contain further spread through proactive vector surveillance and vector control activities targeting transport hubs and routes.[50]

Climate

On the basis of our analysis, climate is an important driver for a number of IDTEs, and climate analysis can be used to anticipate potential threat events.[6,7,19,56] For example, climate has been implicated in IDTEs involving WNF, malaria, dengue and chikungunya fevers, leptospirosis, cryptospirosis, hantavirus fever, Rift Valley fever, norovirus infections, and Q-fever.[6,19,56] The incidence of WNF was reported from several countries in Europe and the link with climatic factors has been examined.[57–60] In 2010, southeastern Europe was afflicted by a large outbreak of WNF, with continuing transmission in subsequent years. Remotely sensed temperature abnormalities, the state of vegetation and water bodies, and bird migratory routes were found to be predictors of WNF risk in a multivariate model.[60] Using this model, short-term projections have been produced with predictive maps of the probability of WNF on the basis of temperature anomalies for July in 2014 and 2015.[59] Climate change projections for 2025 reveal a higher probability of WNF outbreaks, particularly at the edges of the current transmission areas, and further expansion by 2050.[59] These risk maps can be a useful tool for predicting and managing WNF outbreaks and can be used as early warning systems by using July temperature abnormalities to delineate the geographic range of WNF outbreaks later on in the season;[59] public health interventions can then be targeted to areas of increased risk in order to contain or interrupt transmission.

Limitations

As discussed, the IDTE categories and driver groupings of the two studies were not identical.[10,15] However, the revised categories and groupings for the observed data were derived from the foresight study, and the studies were sufficiently similar to reveal some noteworthy differences.

Mortality and morbidity from the observed IDTEs presented should be considered as indicative, as figures are based on the process of gathering epidemic intelligence, which is subject to media coverage, monitoring cycles, diagnostic procedures, and sensitivity of surveillance systems, among other factors. More accurate data on mortality and morbidity from infectious diseases in Europe can be found in the annual epidemiological report produced by the ECDC.[61] The extent to which some IDTEs are captured by epidemic intelligence is also affected by a degree of bias. For example, epidemic intelligence will not capture healthcare-associated IDTEs to the same extent as point prevalence surveys of healthcare-associated infections in acute care hospitals because of reporting disincentives.[36]

Summary

It is desirable to detect IDTEs early to enable a rapid public health response. Monitoring the underlying drivers of IDTEs through risk-based surveillance can identify epidemic precursors, improve the sensitivity of early case detection, and accelerate the response. In addition, interventions that directly target these underlying drivers could reduce the risk of IDTEs occurring in the first place. Thus, analysis of the underlying drivers of IDTEs in Europe can strengthen vigilance against epidemic threats and preparedness activities.

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Conflicts of interest

The authors declare no conflicts of interest.

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