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Use of media and public-domain Internet sources for detection and assessment of plant health threats

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Event-based biosurveillance is a recognized approach to early warning and situational awareness of emerging health threats. In this study, we build upon previous human and animal health work to develop a new approach to plant pest and pathogen surveillance. We show that monitoring public domain electronic media for indications and warning of epidemics and associated social disruption can provide information about the emergence and progression of plant pest infestation or disease outbreak. The approach is illustrated using a case study, which describes a plant pest and pathogen epidemic in China and Vietnam from February 2006 to December 2007, and the role of ducks in contributing to zoonotic virus spread in birds and humans. This approach could be used as a complementary method to traditional plant pest and pathogen surveillance to aid global and national plant protection officials and political leaders in early detection and timely response to significant biological threats to plant health, economic vitality, and social stability. This study documents the inter-relatedness of health in human, animal, and plant populations and emphasizes the importance of plant health surveillance.

Keywords: *surveillance*; *indications*; *early warning*; *crop*; *social stability*; *economic vitality*; *planthopper*; *rice virus*; *waterfowl*; *one health*

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Plant pest and pathogen epidemics can profoundly impact society by affecting food security, human and animal health, and economic stability (1–3). Besides causing natural epidemics, plant pests and pathogens can be used as weapons and for bio-crimes (4–6). Timely information on emerging crop pests and pathogens is abundant and accessible through media and other Internet sources in the public domain (7). Many countries have agricultural extension systems for monitoring and reporting on crop pests and diseases, and outbreaks are increasingly reported by concerned populations as the events are unfolding. While such information does not typically undergo the rigor of (time-consuming) peer review, it has checks and balances. Online information is often subjected to widespread review and comment, which can identify and correct errors quickly (8).

Several biosurveillance systems detect indicators of emerging diseases using online sources (9) and monitor events to provide situational awareness. In this paper, we illustrate the application of one biosurveillance methodology. We illustrate this process with a case study documenting planthopper (Superfamily: Fulgoroidea) infestation and associated transmission of two viruses of rice in Vietnam between February 2006 and December 2007 and China from June to December 2007. The study also describes the role of ducks in managing plant pest and pathogen spread while contributing to zoonotic virus spread in birds and humans.

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Background

Project Argus

Project Argus is a biosurveillance system designed to detect and track biological events that may threaten human, plant, and animal health globally (10). A taxonomy (hierarchical set of concepts) of infectious disease was created using direct, indirect, and enviroclimatic indicators (10–13). Regional specialists fluent in 40 languages collectively utilize taxonomy-based keyword searching and Bayesian tools to identify relevant articles from collected articles. Articles are collected multiple times a day, 7 days a week, from several thousand publically available native-language text-based media sources (14). Event reports are generated from relevant articles and a stage is assessed according to a published heuristic model (12). The resulting reports are reviewed internally according to a documented quality control and assurance protocol. These reports are then posted to a secure Internet portal for Argus users, which can be accessed via http://www.opensource.gov. A complete report archive is maintained for retrospective analyses and refinement of the biosurveillance methodology.

The brown planthopper

The brown planthopper (BPH; *Nilaparvata lugens* (Stål) Family: Delphacidae) is a pest of rice in Asia that reduces rice yields at high infestation levels (15). The BPH is also a vector of rice grassy stunt virus (RGSV) and rice ragged stunt virus (RRSV) (16). Outbreaks of several planthopper species, but predominantly BPH, occurred in a number of East Asian countries in 2005–2008 (17,18), reducing rice production by approximately 3.4M tons in China, Korea, Japan, and Vietnam in 2005–2007 (17). This is significant because rice is a staple food for the vast majority of people in the affected countries (19,20). Moreover, China is the world's largest producer of rice, producing 29% of the world's rice in 2006 (21).

Among the methods used to control BPH in China and Vietnam, this study paid particular attention to the use of free-ranging ducks (22,23), which feed on BPH, as Argus was also monitoring the spread of highly pathogenic avian influenza (HPAI H5N1).

Methods

Information in the public domain and available on the Internet was monitored prospectively between February 2006 and December 2007 to identify direct and indirect indicators of plant pest and pathogen threats to food crops. Native language sources in South-East Asia, as well as English sources were surveilled daily. Upon identification of the BPH outbreak in Vietnam and later China, surveillance was focused on Vietnamese and Chinese language sources in these countries. Public domain Internet sources included news media, university extension sites, blogs, business reports, other biosurveillance systems (e.g. ProMED (24)), and official sources utilized for validation (e.g. Food and Agriculture Organization [FAO] of the United Nations [UN] alerts (25)). Official sources are defined as government or international non-governmental organization [NGO] reports and peer-reviewed scientific journal articles. Previous experience suggests that the combination of English and native language sources is important for full coverage of an emerging event. Therefore, the study used over 180 Vietnamese and 580 Chinese language sources, respectively, and over 2,000 English language sources.

For plant biosurveillance, direct indicators include specific reports of plant pest or disease outbreaks. Indirect indicators are events resulting as a consequence of a plant pest or pathogen epidemic (e.g. pesticide shortage, farmer anxiety, food shortage). They are associated with progression, severity, or level of social disruption caused by an outbreak and may provide early warning of a new event or escalation of a known event (10,11,13). Tables 1a and 1b show examples of direct and indirect indicators used in this study. Automated and predefined keyword combination searches based on the direct and indirect indicators (10,11,13) were performed in English, Chinese, and Vietnamese.

A model representing the evolution of a plant pest or pathogen outbreak and associated societal disruption responses was employed to serve as a guide for analysis and interpretation (Table 2). In this model pre-event conditions (Stage A) may lead to a contained epidemic (Stage 1). Societal indirect indicators escalate in stages toward societal strain as an event progresses from unifocal (Stage 1) to multifocal (Stage 2) to multifocal with infrastructure strain (Stage 3) to eventual social instability or collapse (Stage 4). Recovery indicators (Stage R) reflect a return to normal conditions following a plant pest or pathogen epidemic. In this study, events at

Table 1a. Examples of direct indicators used in the Project Argus Model for use of media and public domain Internet sources

Direct indicators	Code
Confirmed diagnostic results from government recognized official laboratories	D
Specific, unique, or unexpected symptoms or host susceptibility	D
Incidence	D
Severity	D
Crop loss	D
Yield loss measurements	D

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Table 1b. Examples of indirect indicators used by the Project Argus Biosurveillance System for use of media and public domain Internet sources

Indirect indicators	Examples	Code
Official acknowledgment	An indigenous government communicating threat information to its citizens and trade partners (commerce)	1
	Acceptance or declaration of an event; denial or no response	
	Recommendation for a control strategy	
Official action	An indigenous government's response to a plant pest and disease outbreak	2
	Official investigations	
	Implementation of countermeasures	
	Information suppression	
	Prosecution of individuals, organizations, or companies relating to activities in black markets	
Demand for control and countermeasures	Shifts in supply and demand	3
	Mobilization of resources	
	Requests for assistance to control pests	
	Seeking behavior as stockpiles deplete (e.g. traveling to acquire food, seed, or pesticides); innovative mitigation behaviors (e.g. use of homemade pesticides)	
Local perception of threat	Mention of anxiety; farmer pleas for assistance; increased suicide rates	4
	Hoarding; panic buying	
	Loss of confidence in government; news editorials, protests, or rioting	
Changes in business practices	Changes in import/export patterns	5
	Changes in choice of crops grown	
	Profiteering, black market development, price increases; changes in advertising	
Integrity of infrastructure	Market closures; empty store shelves; diminished pesticide, seed, or other critical supplies or delays in distribution; access of stockpiles	6
	Riots; establishment of martial law	
	Open rejection by farmers of government recommendations or orders	

a given time are categorized at the highest stage present (e.g. if an event is multifocal, but demonstrates infrastructure collapse, then it would be considered to be stage 4). These stages and examples are summarized in Table 2. For the purposes of this study 'epidemic' is defined as an escalating plant pest or pathogen outbreak.

Results

Case study: rice pest and pathogen epidemics in Vietnam and China summary of events and sources

Over 5,000 total articles and 239 unique articles (i.e. articles providing new information) on rice pest

Table 2. Project Argus Plant Staging Model

Stage	Description	Example
Stage A	Preparatory, conducive or predisposing conditions, pre-epidemic	Public awareness campaigns; import bans; forecasts of reduced crop production
Stage 1	Unifocal plant pest or pathogen outbreak (outbreak in one community)	Pest outbreak destroys crops on several farms in a single village; drought affecting crops in a single village
Stage 2	Multifocal plant pest or pathogen outbreak (outbreak in multiple communities)	A plant pest or disease outbreak affecting more than one village
Stage 3	Multifocal plant pest or pathogen outbreaks with infrastructure strain	Food shortage, food aid requested, or food aid sent because a pest outbreak, drought, or flood has destroyed crops
Stage 4	Multifocal plant pest or pathogen outbreaks with infrastructure collapse	Industry-wide business closure, financial collapse, mass migration, food riots, looting of grain stores, collapse or change of government
Stage R	Recovery of societal stability, end of epidemic	Official statement of recovery; report of people returning to farm land after a massive outbreak has ended and the food supply has been restored

Table 3. Summary of the search results for a case study of brown planthopper and rice grassy stunt or rice ragged stunt in rice in Vietnam and China in 2006–2007

Country	Language	Total articles	Unique articles[1]	%
Vietnam	Vietnamese	1,984	123	94.8
Vietnam	English	104	31	5.2
China	Chinese	3,026	81	98.5
China	English	46	4	1.5

[1]Unique articles are defined as articles that provide new information and are not reproductions or summaries of other articles.

and pathogen epidemics were identified during the study period. Official government or international (NGO) reports and peer-reviewed scientific journal articles were used to verify information accuracy. Table 3 summarizes the article pool resulting from the searches. The specific sources cited and their indicators are provided in Tables 4, 5 and 6.

Internet media observations on planthoppers and virus diseases in Vietnam

Direct, indirect indicators, and associated stages concerning the BPH-virus epidemic in rice in Vietnam in 2006 are summarized in Table 4. In February 2006, as the 'Winter-Spring' crop approached harvest, BPH had infested nearly 65,000 ha in 16 of 58 provinces (Table 4_2006a). During the next crop rotation 'Summer-Autumn', BPH populations escalated between March and July (Table 4_2006b, c). Between October and late November 2006, government requests to implement a crop-free period to break the pest life cycle were ignored (Table 4_2006d). Devastation of the new 'Winter-Spring' crop lead to a state of emergency, triggering government assistance, export restrictions, and access to the national rice stockpile enabling the rice market to recover by December 2006 (Table 4_2006e–i).

In February 2007, public Internet media reported that the government urged farmers in the Mekong River Delta to destroy heavily infested rice fields and not plant the 'Summer-Autumn' rice crop to interrupt the pest life cycle (Table 4_2007a). By March, the Ministry of Agriculture and Rural Development (MARD), fearing that the BPH affected area could be 100 times larger than the previous year, reversed its earlier request to cancel the 'Summer-Autumn' rice crop (Table 4_2007b, c). The FAO funded a project to help Vietnamese farmers control BPH while other farmers sought off-farm employment due to drought (Table 4_2007d, e). The epidemic escalated to levels 10-fold higher than 2006 (Table 4_2007f). Local, state, and federal governments established mandates and assistance programs to control the BPH, curb speculation, profiteering, and absenteeism on farms (Table 4_2007g–i). Traffic, businesses, and homes were disrupted by massive flight clouds of BPH (Table 4_2007j). By October the Minister of Agriculture again restricted exports and accessed over 685 tons from the national rice stockpile to prevent societal strain (Table 4_2007k–m). This assistance and control protocol meetings led to stabilization and recovery of the rice supply and rice market (Table 4_2007n, o). During this year, RRSV and RGSV were confirmed in Vietnam by the International Rice Research Institute (IRRI) through the FAO assistance program (17,26).

Planthoppers in China

During 2007, BPH migrated from Vietnam to China in large numbers. Direct, indirect indicators, and stages are summarized in Table 5. In June 2007, media reported that 1.2 million ha of rice fields in South China were infested with planthoppers (species unspecified)—a 40% increase over the previous season (Table 5_2007p). Media described BPH spreading from south to central to east China. By July 25, flooding, followed by BPH, caterpillars, and other pests affected 2.8 million hectares of paddy in Anhui province, Eastern China, causing US $800M damage, triggering authorities to activate emergency agricultural disaster plans (Table 5_2007q, r). The government allocated US $1.3M for BPH control operations (Table 5_2007r). Media reported that BPH invaded nearly 400,000 of the 1M hectares of rice in Sichuan province, Central China (Table 5_2007r). In Hubei, authorities reported that planthopper populations (mixed species) were higher in 2007 than in 2006, but due to early preventive measures (US $2.6M), crop losses would be less than in 2006 (Table 5_2007s). However, in Changsha, Hunan, southwest of Hubei, BPH populations were 60% higher than in 2006 despite planthopper control efforts (Table 5_2007t).

In mid-October, reports of BPH continued from across southern China, but BPH populations were generally reported as lower than in 2006. From September to December, 115 local and regional articles focused on BPH control successes and on methods of preventing outbreaks stating that the epidemics were mitigated, leading to recovery. Chinese authorities promoted the use of light traps, fish, and ducks to control rice pests. One article on November 7, 2006 indicated that researchers were introducing a new 'one rice [paddy] two ducks' method, where at least two ducks are released into every quarter hectare of rice paddy (Table 5_2007u). The method reportedly controlled insect pests in the fields.

Avian Influenza in Vietnam

In Vietnam, media reports of sick, free-ranging ducks coincided with reports of avian influenza outbreaks. Direct, indirect indicators, and stages are summarized

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Table 4. Sources and indicators referenced in open source planthopper-virus case study in Vietnam, 2006–2007*

Citation	Date	Source	Language	Indicator	Stage	Indicator Code
2006a	February 12, 2006	Vietnam News	English	Ministry of Agriculture and Rural Development (MARD) reports BPH infested 65,000 ha in 16 provinces, local agencies implement controls; pesticide price hikes seen.	PS2	1 D 2 5
N/A	March 1, 2006 to March 31, 2006	Multiple	Multiple	'Winter-Spring' crop harvested; crop loss reported	PS3	D
2006b	April 2, 2006	Thanhnien News	English	MARD announced a 335,000 ton shortfall in the harvest due to the BPH; exports capped at 5M tons.	PS3	1 D 6
2006c	July 24, 2006	Vietnam Net	English	MARD acknowledges Mekong Delta infested with BPH, RGSV, and RRSV; 2 week increase from 27,000 ha to 38,000 ha affected; issued 70,000 bottles pesticide to farmers; recommended BPH-resistant varieties; destroyed fields over 30% affected; farmers compensated.	PS2	1 D 2 2 2
N/A	October 1, 2006 to October 31, 2006	Multiple	Multiple	'Summer-Autumn' crop harvested; crop loss reported	PS3	D
2006d	October 20, 2006	Thanhnien News	English	Local experts warn that the country's food security is in jeopardy; BPH damage > 10% southern crop (65,000 ha); request that infested cropland be left uncultivated largely ignored.	PS3	1 2 6
2006e	October 23, 2006	Vietnam Economy	English	The Vietnamese Prime Minister (PM) declared emergency; officials take action; cancelled travel and meetings.	PS3	2 2 2
2006f	October 30, 2006	Vietnam Net	English	Over 72,000 of 123,645 ha of the new rice crop in Mekong delta affected by BPH. Farmers refused to destroy infested paddy.	PS3	D 6
2006g	November 5, 2006	Thanhnien News	English	PM mobilizes all human resources for pesticide spraying; BPH and RRSV spread to 21 provinces, >500,000 ha rice affected; US $125M in losses.	PS3	3 D D
2006h	November 13, 2006	Thanhnien News	English	PM orders ban on export of rice to preserve food security; prevent price hikes, punish offenders. Finance Minister sells rice from national stockpile to stabilize the market.	PS3	5 2 6

Table 4 (*Continued*)

Citation	Date	Source	Language	Indicator	Stage	Indicator Code
2006i	November22, 2006	Thanhnien News	English	PM authorizes export of rice to reduce damage to industry but fears 700,000 tons loss of rice production; reduced exports by 500,000 tons, punishes rice speculators.	PSR	5 6 2
2007a	February 27, 2007	Vietnam Net	English	MARD urged farmers in Mekong River Delta to destroy rice fields heavily infested by BPH.	PS2	2
2007b	March 12, 2007	Vietnam's Farmer's Union	Vietnamese	MARD officials indicated that BPH/RRSV could affect an area 100 times greater than the previous year.	PS2	1
2007c	March 28, 2007	Radio Free Asia	Vietnamese	The government reconsidered its earlier request to cancel the 'Summer-Autumn' rice crop	PS2	2
N/A	April 1, 2007 to May 16, 2007	Multiple	Multiple	19 Vietnamese media reports of escalation of the epidemic.	PS2	D
2007d	April 16, 2007	Tienphong Online	Vietnamese	The United Nations (UN), Food and Agriculture Organization (FAO) funds a USD $100,000 project to help farmers in the Mekong Delta control rice pests: first indication of international assistance.	PSR	2
2007e	April 19, 2007	Community Party of Vietnam Online Newspaper	Vietnamese	As drought destroyed rice crops, farmers sought off-farm employment.	PS3	4
2007f	May 7, 2007	Vietnam Ministry of Natural Resources and Environment	Vietnamese	Epidemic 10 times more severe than previous year, 80,000 ha of rice infested with BPH (including 16,000 ha heavily infested at 10,000 BPH/m^2).	PS3	D
2007g	May 9, 2007	Vietnam Net	Vietnamese	Minister of Agriculture and provincial officials help farmers; surveillance, pesticides, and training; farmers abandon fields.	PS3	2 4 6
2007h	May 12, 2007	Vietnam News	English	First English report since February on the 2007 BPH epidemic. MARD indicates 80,000 ha rice affected by BPH; MARD encourages local officials to supervise pest management; government attempts to curb price hikes of pesticides and rice.	PS3	1 2 2 2
N/A	May 18, 2007 to June 25, 2007	Multiple	Multiple	BPH damage escalates in Vietnam; seven articles	PS3	D
2007i	June 26, 2007	Vietnam's Farmer's Union	Vietnamese	Over 18% Spring rice crop in Cau Ke district with RGSV	PS3	D

Table 4 (Continued)

Citation	Date	Source	Language	Indicator	Stage	Indicator Code
2007j	July 20, 2007	Baomoi	Vietnamese	BPH infested 126,000 ha of the 'Spring-Autumn' paddy harvested; presents threat to 700,000 ha newly planted paddy in the Mekong Delta; BPH flights close businesses, cause auto accidents.	PS3	D 5 6
2007k	August 16, 2007	Nguoi Lao Dong Online	Vietnamese	More than 130,000 ha crop infested by BPH, Mekong Delta.	PS3	D
2007l	October 5, 2007	Vinagency	Vietnamese	PM restricts exports; rice prices rise	PS3	5 6
2007m	October 8, 2007	Vietnam Economy	English	PM distributes an additional 555 tons of rice from national stockpile to assist farmers who lost their crops to BPH.	PSR	6
2007n	November 8, 2007	Vietnam News	English	Plant protection agencies from 22 southern provinces meet in October to establish disease prevention protocols.	PSR	2
2007o	November 28, 2007	Laodong	Vietnamese	Government distributes 130 tons of rice to help farmers recover from the loss of paddy crop due to BPH.	PSR	6

*Note that this table contains greater detail regarding sources and indicators than is described in the text of the case study.

in Table 6. An article published on December 19 indicated that on December 6, 2006, southern Vietnam provincial officials detected Vietnam's first outbreak of Highly Pathogenic Avian Influenza Virus (HPAI) H5N1 of 2006. Over 7,000 chicks and ducklings were culled in Cau Mau and Bac Lieu provinces, southern Vietnam (Table 6_2007j). On December 27, 2006 the government declared the HPAI outbreak to be contained and banned free-ranging ducks in the Mekong Delta (southern Vietnam), but raised concerns over illegal poultry smuggling from China to Vietnam (Table 6_2007k).

On February 28, 2007, media observed that Vietnam lifted a 2005 ban on hatching ducks and geese, even though a new outbreak of HPAI H5N1 in northern Vietnam (Hai Duong province) was reported that week (Table 5_2007v). However, movement of ducks was banned. Prior to lifting the ban on hatching ducks, farmers continued using free-range waterfowl to control insects in rice fields, with an estimated population of over 60M waterfowl in the country. Later, a peer-reviewed publication indicated that the ban on hatching ducks presented problems for vaccination crews because people were hesitant to present illegal waterfowl for vaccination (27). On February 28, media reported that 50 ducks were found dead on a farm in Tra On district (southern Vietnam). The birds had been taken there from Soc Trang, southern Vietnam to feed in recently harvested fields (Table 6_2007v). On March 12, 2007, Internet media reported that the HPAI H5N1 strain in Vietnam was found to be the same strain that was previously found only in China to the north of Vietnam (Table 6_2007w).

On June 29, 2007, it was reported that 435 H5N1-infected ducks from Mo Dao commune, in northern Vietnam, were destroyed by officials. In Que Vo district, Bac Ninh, in northern Vietnam, media reported that free-range ducks began dying; at least 100 duck carcasses were found in local rice paddies. Duck ownership was unclear. Concern was expressed by the locals about slow government response and unsafe water sanitation (Table 6_2007x). On October 15, 2007, it was observed that the Vietnamese government launched a campaign to fight avian influenza along with rice pests and pathogens (Table 6_2007y). Over the next few months, millions of ducks across Vietnam were vaccinated against avian influenza. In December, 2007, residents in Bac Lieu Province, southern Vietnam, expressed concern over the potential spread of avian influenza as unvaccinated ducks freely roamed paddies throughout the province, despite regulations requiring all unvaccinated ducks to be isolated and confined to farms. Local duck farmers complained that some officials were taking bribes and allowing unvaccinated ducks from other provinces to roam in their area.

Table 5. Sources and indicators referenced in open source planthopper-virus case study in China, 2007*

Citation	Date	Source	Language	Indicator	Stage	Indicator code
NA	June 5, 2007 to July 25, 2007	Multiple	Multiple	Planthopper damage spreads across China as reported in 13 articles (species unspecified).	PS2	D
2007p	June 6, 2007	China View	English	Planthoppers infest 1.2 million ha rice in south China, 40% increase from last year. Ministry of Agriculture says planthoppers (species unspecified) flew from abroad 2 weeks earlier than last year.	PS2	D 1
2007q	July 25, 2007	Anhui News	English	In Anhui, flooding, pests cause USD $800 million damage; RRSV, RGSV, rice leaf rollers, and planthoppers (species unspecified) affect 2.8 M ha; rice production could drop by 30%–40%.	PS3	D
2007r	July 29, 2007	China Agricultural Product Network	Chinese	Authorities in Sichuan Province activate Level II Emergency Alert.	PS3	2
2007r	August 7, 2007	China Agricultural Product Network	Chinese	Planthoppers (species unspecified) spread to 19 cities and 94 counties threatening 390,000 ha of cropland in Sichuan. The province declares a Level II alert; activates emergency agricultural disaster plans on July 29th including 24-hour headquarter operations, expert analysis, press releases, 1,300 light traps, and USD $1.3 million in funding for BPH control.	PS3	D 2
N/A	August 8, 2007 to December 31, 2007	Multiple	Multiple	Over 115 articles report outbreak levels; local and provincial authorities promote measures to prevent outbreaks, including the use of ducks.	PS3	D 2
2007s	September 15, 2007	China Agricultural Product Network	Chinese	Hubei spends USD $2.6M on planthopper control; density of planthoppers (mixed species) higher than previous year, yet damage lower than 2006 due to aggressive control.	PS2	2 D
2007t	28-September-07	Hubei TV	Chinese	Planthopper densities (species unspecified) in Changsha, Hunan 60% higher than 2006.	PS2	D
2007u	November 7, 2007	Farmer Daily Newspaper	Chinese	Researchers promote pesticide alternatives such as fish, ducks, and light traps to control planthoppers (any species).	PSR	2

*Note that this table contains greater detail regarding sources and indicators than is described in the text of the case study.

Table 6. Summary of direct and indirect indicators obtained from public domain Internet sources for the relationship between ducks and *Highly Pathogenic Avian Influenza* (HPAI H5N1) epidemic in Vietnam, 2006–2007*

Citation	Date	Source	Language	Indicator	Stage	Indicator Code
2006j	December 6, 2006	Foreign Broadcast Service	English	First HPAI H5N1 outbreak of 2006 in Vietnam; >7,000 chicks and ducklings culled; raising ducks was banned in 2005 to curb spread of HPAI H5N1; provincial leaders claim dead birds 'hatched illegally'.	PS2	D 2 1
2006k	December 27, 2006	The Age (Australia)	English	The government declared the HPAI H5N1 outbreak contained; poultry smuggled from China to Vietnam.	PSR	1 5 3 2
2007v	February 28, 2007	Vietnam Express News	Vietnamese	Movement of poultry in the Mekong Delta banned as free-ranging ducks identified as major source of HPAI H5N1 spread, but lifts ban on hatching ducks. Fifty unvaccinated ducks found dead on farm test positive for H5N1; birds taken from Soc Trang to Tra On to feed in recently harvested fields, just days after a new HPAI H5N1outbreak in North Vietnam.	PS1	2 D 6
2007w	March 12, 2007	China View	Vietnamese	The strain of HPAI in North Vietnam is the same as China strain.	PS2	D
2007x	June 29, 2007	Vietnam Ministry of Natural Resources and Environment	Vietnamese	435 H5N1-infected ducks from Mo Dao commune destroyed; hundreds of free-range ducks in Bac Ninh dying; 100 duck carcasses in paddies; no one will admit owning the ducks; contaminated water and slow response concerns.	PS2	2 D 4 6
2007y	October 15, 2007	Tienphong Online	Vietnamese	The Vietnamese government launched a campaign to prevent AI along with rice pests and diseases.	PS2	2
2007z	December 20, 2007	Voice of Vietnam	Vietnamese	Residents express health concerns over unvaccinated ducks roaming freely; request government assistance.	PS2	4 3

*Note that this table contains greater detail regarding sources and indicators than is described in the text of the case study.

Discussion

In this study, the severity of an epidemic was recognized as the epidemic unfolded by monitoring media on the Internet and by categorizing direct and indirect indicators into established stages of epidemic progression. The surveillance methodology utilized was adapted from animal and human disease biosurveillance and represents a novel approach to crop surveillance.

Validation sources

The estimates of crop losses and areas affected in the Internet news media were validated by official government or international NGO reports and peer-reviewed scientific journal articles (Table 7). It is important to note that often events appeared in the Internet media before the official publications (Fig. 1). Though official reports and peer-reviewed research papers may present highly

Table 7. Validation of public domain Internet media reports by official reports

Date	Public domain Internet media report	Date	Official sources
April 2, 2006	335,000 ton shortfall in harvest, Vietnam (Table 4_2006b)	May 2008	700,000 tons less rice than 2005–2006 (17)
November 13, 2006	Exports halted in Vietnam (Table 4_2006h)	May 2008	Exports temporarily halted in Vietnam
November 22, 2006	PM fears 700,000 ton loss, exports reinstated (Table 4_2006i)	June 2007	855,000 tons loss in Vietnam 2005–2006 (34)
	38,000 ha rice with BPH (Table 4_2006c)	October 2006	BPH, RRSV, RGSV confirmed in Vietnam (26)
July 24, 2006	RRSV and RGSV in Vietnam (Table 4_2006c)	May 2008	BPH, RRSV, RGSV confirmed in Vietnam (17)
	Pesticides provided and distributed; assistance in control offered; farmers compensated for destroyed crops (Table 4_2006c)	May 2008	$6.6 in farmer assistance in control and training (17)
February 28, 2007	Prior to lifting the ban on hatching ducks, farmers continued using free-range waterfowl to control insects in rice fields in Vietnam (Table 6_2007v)	June 2009	People hesitant to present illegal waterfowl for vaccination during Vietnam ban (27)
December 27, 06	Concern of smuggled ducks bringing H5N1 from neighboring countries into Vietnam (Table 6_2006k)	March 2010	An exotic clade of H5N1 detected in poultry seized at northeastern ports of entry into Vietnam and, subsequently, in live bird markets near Hanoi underscores need for AI surveillance at borders and markets where smuggled birds may be sold (35)
March 12, 2007	Northern Vietnam strain of H5N1 is same as China's (Table 6_2007w)	April 2008	Cambodian strain of H5NI in southern Vietnam and Chinese strain of H5N1 in northern Vietnam due to movement of ducks (28)
April 16, 2007	FAO funds $100,000 to help Vietnam rice farmers (Table 4_2007d)	May 2008	FAO funds $100,000 to help Vietnam rice farmers (17)
November 5, 2006	$125M rice losses in Vietnam; $ >500,000 ha affected in Vietnam (Table 4_2006g)	June 2007	$120M rice losses in South Vietnam 2005–2006 (34); >485,999 ha affected South Vietnam 2005–2006 (34); 210,000 ha affected in Mekong Delta 2006 (36)
	Sichuan Province activates Level II Emergency (Table 5_2007r)	July 2009	Sichuan Province activates Level II Emergency (37)
July 29, 2007	Sichuan 390,000 ha threatened (Table 5_2007r)	January 2010	Sichuan 390,000 ha threatened (38)
June 6, 2007	1.2M ha rice in South China infested with BPH (Table 5_2007p)	June 2007	BPH infested over 1.2 ha of rice in South China by June 6, 2007 (39)
June 6, 2007	Migration of planthoppers from Vietnam to Southern China 2 weeks earlier than the previous year (Table 5_2007p)	August 2008	Documented BPH migrations from Vietnam to China 2005–2007 (40)
July 25, 2007	30%–40% losses in Anhui due to BPH (Table_2007q)	July 2007	30%–40% losses in Anhui due to BPH (41)
September 28, 2007	Hunan planthopper densities 60% more than 2006 (Table 5_2007t)	December 2007	Changsha city Hunan densities 60% higher than 2006 (42)

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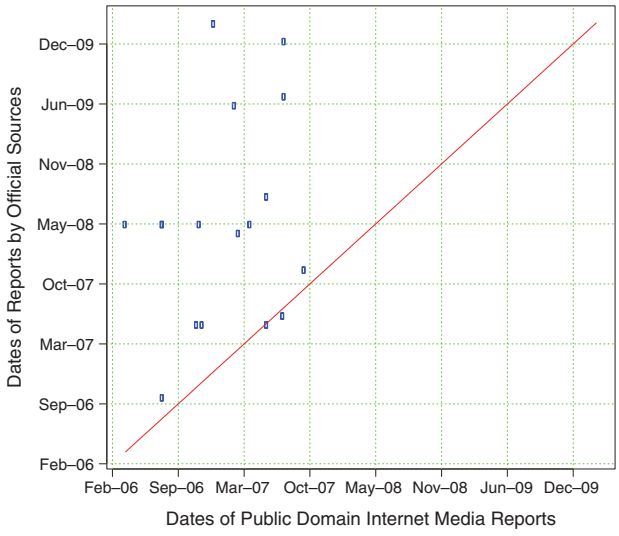

Fig. 1. Comparison of dates of Internet media reports and reports from official sources. Data above the diagonal line correspond to the case when a public domain source reports on an event before an official source reports on the same event. Below the line, an official source reports on an event before a public domain source.

accurate details and results at a highly technical level, the time required to conduct the research and publish it is months or years. For example, in Vietnam there were delays of one or more years after the case study was completed before official publications reported the estimates of the infestation or infection severity and crop loss (17). The power of the approach of using Internet sources for surveillance is that such information is available in hours to days following events. This is essential for early warning and situational awareness.

Indicators and staging

In this study, many of the sources reported direct indicators of outbreaks (e.g. number of hectares affected, percentage of yield reduction). However, indirect indicators were also reported. As the BPH-RRSV/RGSV epidemic emerged, indirect indicators included official acknowledgement of the outbreak; official action as government assistance with pesticides, training, food security, control strategies, and mandates; demand for countermeasures from the farmers in terms of public assistance; perception of threat (e.g. hoarding of pesticides, migration to cities for work); change of business practices (e.g. export restrictions, price gouging, profiteering); and strain on infrastructure integrity (e.g. rice stockpiles accessed, criminal activities such as rice, duck, and pesticide smuggling, and refusal to follow government pest control mandates).

Each report was staged based on the degree of pest or pathogen spread and associated social disruption (Table 2). Report staging over time is illustrated in Figs. 2a and 3a for Vietnam and China, respectively. In 2006, the BPH/RRSV-RGSV outbreak was first reported as a stage 2 on February 9, 2006 in Vietnam, and escalated to stage 3 on March 2, 2006 as food and societal infrastructure strain developed due to Vietnam's shortage of rice and food insecurity. Increased staging suggests escalating social pressure and infrastructure strain. Recovery was initially observed on November 22, 2006 when assistance arrived (e.g. training and pesticides provided, and rice stockpiles released by national government; FAO and IRRI scientists collaborating with Vietnam government scientists). In China, media reported events indicating that the epidemic escalated from stage 2 to stage 3 in less than a month (June 5 to June 25, 2007) and returned to stage 2 in mid-September 2007 when the government provided US $3.9M in aid, which may have facilitated the end of the epidemic and eventual recovery in November 2007. Fig. 2b and 3b demonstrate that multiple indicators are represented at each stage. Thus, both direct indicators, present throughout the study period (Tables 4 and 5), and indirect indicators are required to understand events such as those described in this case study.

Inter-relatedness of human, plant, and animal health

This case study documents the inter-relatedness of health in human, animal, and plant populations. The reporting described above suggests that BPH-vectored virus epidemics encouraged illicit movement and breeding of free-range ducks for the purpose of BPH control. In 2008, molecular sequence analysis indicated the China H5N1 strain was in northern Vietnam and the Cambodian strain was in southern Vietnam (28), suggesting that duck trade had introduced the virus from neighboring countries. Infected ducks excrete influenza viruses while living in paddies, providing a potential human and animal health concern to the public exposure to infectious water. Avian influenza virus is transmitted between ducks orally through water contaminated with feces (29,30). In 2008, FAO announced that ducks, people, and rice paddies—rather than chickens—are the major factors driving outbreaks of HPAI H5N1 in Thailand and Vietnam (31–33). Previous studies associate the spread of H5N1 with the movement of ducks at the end of the rice harvest (31,32). That model, however, would not explain the spread of HPAI H5N1 during the rice cropping season as observed in the present study. Our working hypothesis is that ducks were herded into rice fields (while rice was still growing in the fields) to feed on BPH and other insects, such that the spread of HPAI H5N1 roughly followed the spread of BPH (31).

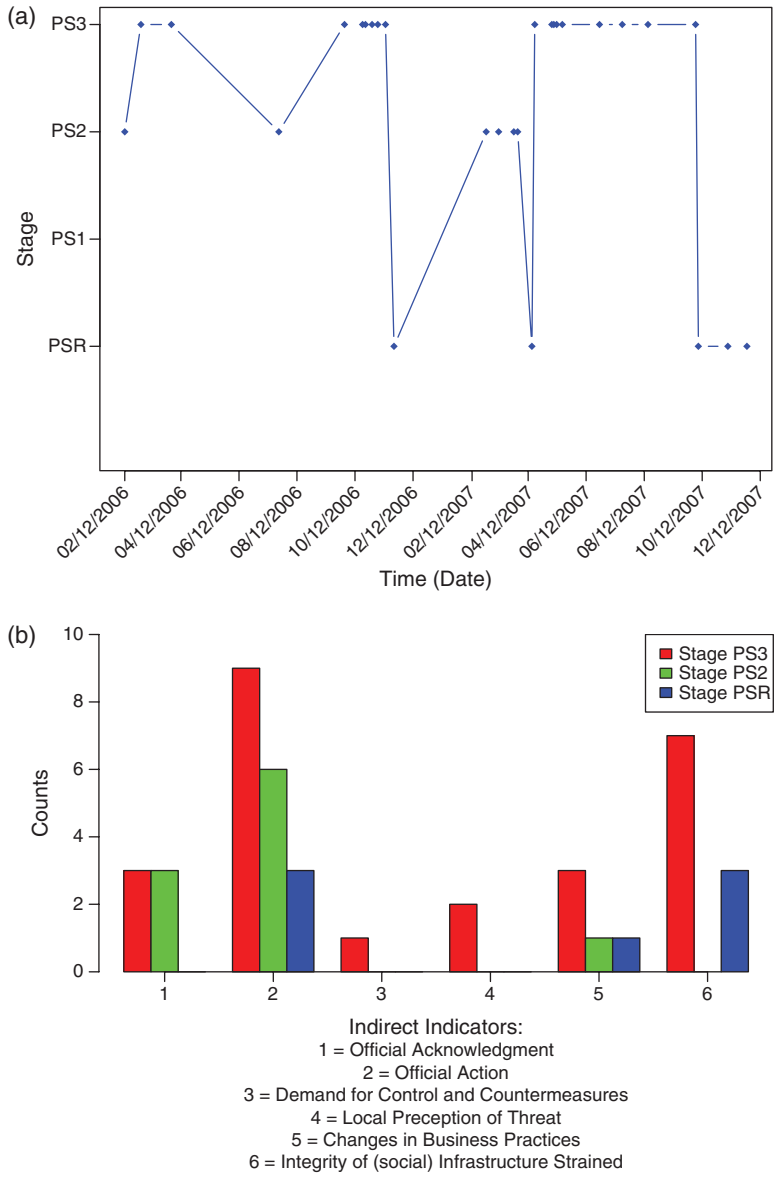

Fig. 2. (a) Stage over time for the 2006–2007 case study of planthopper-virus in Vietnam. (b) Frequency of indirect indicators by stage for the 2006–2007 case study of planthopper-virus in Vietnam.

Significance of public media monitoring in identifying emerging epidemics

Plant pest and disease epidemiology has largely relied on field-collected direct measurements to assess the development and severity of outbreaks. This study demonstrates that Internet sources can provide important information for monitoring plant pest and pathogen epidemics at the local level. The methodology described here, employing staging of indirect as well as direct indicators, provides a focus on signatures in the media typical of emerging or escalating epidemics (13,14). This approach can be utilized to detect outbreaks early, before official reports and studies are published and particularly where on-the-ground reporting is limited and where the media is available. We believe this study is the first to use Internet sources to document the impact of plant pest and pathogen epidemics on resource allocation and social stability.

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Conflict of interest and funding

The authors have not received any funding or benefits from industry to conduct this study.

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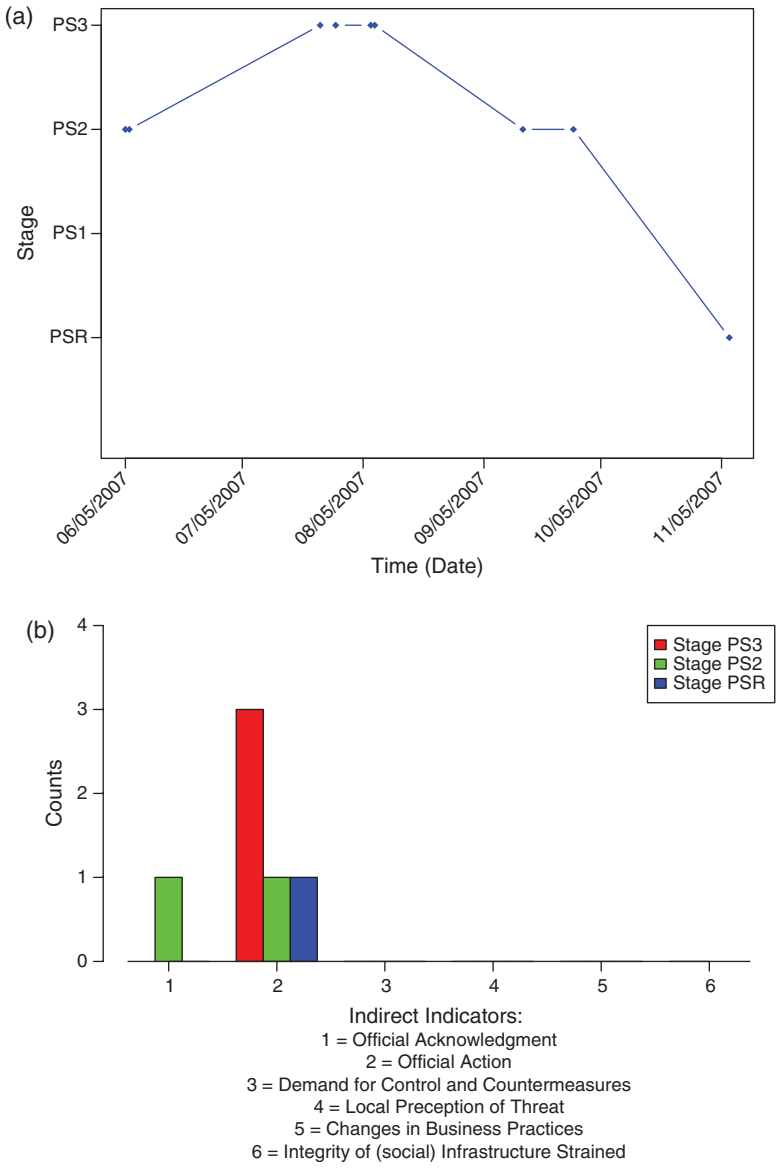

Fig. 3. (a) Stage over time for the 2007 case study of planthopper-virus in China. (b) Frequency of indirect indicators by stage for the 2007 case study of planthopper-virus in China.

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