

Coupled Natural-Human Systems and Emerging Infectious Diseases: Anthropogenic environmental change and avian influenza in Vietnam

1. Introduction

Unraveling mechanisms that underlie new and reemerging infectious diseases (EID) requires exploring complex interactions within and among coupled natural and human (CNH) systems and poses one of the most difficult scientific problems facing society today (Wilcox and Colwell 2005). EID are diseases that have recently increased in incidence or in geographic or host range (e.g., tuberculosis, cholera, malaria, dengue fever), and diseases caused by new pathogens and new variants assigned to known pathogens (e.g., HIV, SARS, Nipah virus, and avian influenza) (Morse 1995). Wilcox and Gubler (2005) and Wilcox and Colwell (2005: 6) argue that transformations in ecological systems caused by multifaceted interactions with anthropogenic environmental changes such as urbanization, agricultural transformations, and natural habitat alterations produce feedbacks that affect natural communities and ultimately their pathogens, animal host, and human populations. These altered ‘host-pathogen’ relationships facilitate pathogen spillover into “new” hosts, rapid adaptations by pathogens, more frequent generation of novel pathogen variants that result in new and reemerging infectious diseases, as well as range expansion and increasing epidemic intensity and frequency of existing diseases.

This project seeks to test the Wilcox-Gubler-Colwell hypothesis by examining whether risks, and perceptions of risk, associated with highly pathogenic avian influenza (HPAI) caused by the H5N1 virus¹, as measured in terms of poultry deaths, can be associated with anthropogenic environmental changes produced by urbanization, agricultural change, and natural habitat alterations. The project will explore this question in the nation of Vietnam utilizing the nation’s strong data collection and management system. This is a novel way of looking at HPAI and other health risks like it, suggesting these risks are not an accident of time and place, but rather are the product of the modernization transition.

This project is a direct response to the NSF Coupled Natural and Human Systems program focus on the complex interactions among natural and human systems at diverse spatial, temporal, and organizational scales, and it will examine how these systems function and the processes through which these systems interact with each other. The project is based on an integrated, quantitative, system-level method of inquiry, and includes the participation of graduate students in an NSF funded IGERT in Ecology, Conservation, and Pathogen Biology as well as scientists from the United States, Vietnam, Thailand, and other countries.

2. Research objectives and science questions

The research team will examine how measures of urbanization, agricultural change, and habitat alteration correlate with outbreaks of HPAI in poultry. The team will also address how humans perceive risk, an important element of CNH systems that has received little attention to date. The understanding of risk is relative; it cannot be measured independent of the cultural context in which it is perceived. Hence the project will explore the complex linkages that exist between people’s perceptions of the risk of HPAI in poultry and the other ecological and social variables in the study.

The specific objectives of this study will be:

1. To test a model that draws on social ecological systems and resilience (SES) and risk transition theories to explore the multifaceted relationship theorized by the Wilcox-Gubler-Colwell hypothesis between anthropogenic transformations such as urbanization, agricultural change, and natural habitat alteration and the emergence and reemergence of infectious diseases. We will test this model in Vietnam using data collected at national, commune, and household scales.

¹ In this document HPAI refers to HPAI caused by the H5N1 strain.

2. To examine the influence of socio-ecological and socio-psychological variables on individuals' perceptions of and responses to the risk of HPAI in traditional, transitional, and modern communes.
3. To integrate this study with education and training programs at the University of Hawaii including the Integrative Graduate Education and Research Traineeship (IGERT) program that focuses on “Integrative Training in Ecology, Conservation and Pathogen Biology”, and the Population Studies Program that examines inter-relationships between population and health and social, cultural, and economic change. The study will also engage health journalists and graduate students with other disciplinary backgrounds at the East-West Center, the University of Hawaii, Manoa, the Hanoi University of Agriculture in Vietnam, and elsewhere in Asia and the Pacific.
4. To establish new collaboration among scientists from multiple disciplines and institutions, and among U.S. academic institutions, industry, government, and international partners from Vietnam and other countries in the Asia Pacific region. We will seek to maintain, operate, and modernize shared research and education infrastructure including the ability of scientists in Vietnam to use new information tools (e.g., large databases, networks and digital libraries). We will develop activities that ensure that multi-user facilities are sites of research and mentoring for large numbers of students.

The overarching research question to be addressed by this proposal is: **How does the outbreak of HPAI as measured by numbers of diseased poultry (chickens) in Vietnam vary across traditional settings (customary agricultural practices and housing), modern settings (agricultural modernization and industrial cities), and transitional settings (chaos of in-between)?** As suggested by SESR and transitional risk theories, the effects of urbanization, agricultural change, and habitat alteration in the CHN system may influence disease outbreaks. To study the transition-disease relationship comprehensively, we need to answer specific questions at different scales and during different phases of the research.

Specific research questions are:

1. Urbanization
 - a. How do measures of urbanization and peri-urbanization assessed nationally at the commune level in the 1989 and 1999 censuses correlate with outbreaks of HPAI in poultry?
 - b. How do transition indices (TIs)² of these measures correlate with HPAI in poultry?
 - c. How do these measures assessed in household and focus group interviews in 36 communes correlate with outbreaks of HPAI in these communes and households?
2. Agricultural change
 - a. How do measures of agricultural change (both crop and livestock) assessed nationally at the commune level in the 2001 and 2006 agricultural censuses correlate with outbreaks of HPAI in poultry?
 - b. How do TIs of these measures correlate with HPAI in poultry?
 - c. How do these measures assessed in household and focus group interviews in 36 communes correlate with outbreaks of HPAI in these communes and households?
3. Habitat alteration
 - a. How do measures of changes in habitat alteration (wetlands) assessed nationally at the commune level from MODIS and AVHRR imagery (250 m to 1 km resolution) correlate with outbreaks of HPAI in poultry?

² We define transition indices (TIs) on page 11.

- b. How do TIs of these measures correlate with HPAI in poultry?
 - c. How do these measures assessed in 36 communes from Aster imagery (15 m resolution) correlate with outbreaks of HPAI in these communes?
4. Risk perception
- a. How do risk perceptions and protective behaviors correlate with observed risk (poultry deaths) as measured via a household survey administered in 36 communes?
 - b. What is the relative importance of socio-ecological and socio-psychological variables in determining perceptions of the risk of HPAI in poultry?
 - c. How do perceptions of and responses to HPAI risk vary across traditional, transitional, and modern settings?

3. Intellectual merit

The Wilcox-Gubler-Colwell hypothesis of disease emergence was influenced by complexity theory which argues that as complex adaptive systems (CAS) CNH systems exhibit far-from-equilibrium non-linear behavior often manifested as “surprise” as with the case of abrupt and unexpected epidemiological phenomena including the emergence of entirely new diseases. Parallel to this, in biological science a re-envisioning has occurred in which nature is no longer seen as consisting of balanced ecological systems made up of relatively linear processes. Rather, natural systems are now seen as hierarchical, self-organized, non-equilibrial and non-linear systems in which emerging diseases can themselves be seen as “emerging properties” of these CAS (Levin 1999). The traditional conception of the ecosystem, a fundamental paradigm in the ecological sciences, has thus been overturned (O’Neill 2001).

As such, ecosystems, including “social ecological systems” are now understood as characteristically producing emergent phenomena like the unexpected appearance of new pathogens, inherently unpredictable by conventional approaches and theory (e.g., epidemiological models). Moreover, nearly all emerging diseases are vector borne or zoonotic (i.e., maintained in natural host-pathogen cycles that “spill over” to humans) (Woolhouse et al 2005). They, or their immediate progenitors, exist as part of naturally co-evolved host-parasite complexes embedded within ecosystems, whose dynamics normally include non-linear, cross-scale behavior (Horwitz and Wilcox 2005). Based largely on complexity theory, SESR theory was developed to account for the non-linear dynamic behavior of CNH systems that result from intervention in “managed” ecosystems that unwittingly lead to unexpected and sometimes catastrophic outcomes, including disease re-emergence.

Holling (1973) introduced the concept of resilience into the ecological literature as a way of understanding nonlinear dynamics, such as the processes by which ecosystems maintain themselves in the face of change. In a resilient forest ecosystem, for example, four phases of change repeat themselves again and again. The first two phases, exploitation (the establishment of pioneering species) and conservation (the consolidation of nutrients and biomass), lead to an old growth forest or a climax community. But this climax community invites environmental disturbances such as fire or disease, and is more susceptible to disturbances than non-climax forests. When surprise or change occurs, the accumulated capital is suddenly released producing other kinds of opportunity, termed creative destruction. Release, a very rapid stage, is followed by reorganization in which, for example, nutrients released from the trees by fire will be fixed in other parts of the ecosystem as the renewal of the forest starts again (Berkes *et al.* 2003: 17-18). Holling suggested that human societies also reproduce and reinvent in the process of cyclic transformations; he writes: “The bewildering, entrancing, unpredictable nature of nature and people, the richness, diversity and changeability of life come from the evolutionary dance generated by cycles of growth, collapse, reorganization, renewal and re-establishment” (Holling 2003:xv).

In the social sciences a body of theory that is relevant to both the Wilcox-Gubler-Colwell hypothesis and Holling's resilience theory, surrounds the notion of various types of development transitions. Nobel Prize winner Simon Kuznets proposed that with respect to inequality, economic development is not linear but rather an inverted 'u' shape; economic development is a transition from an initial state of relative equality to an end state also of relative equality, but in the midst of economic development nation-states display high levels of economic inequality (line C in Fig. 1 is a Kuznets curve). While various scholars have shown that Kuznets curves are not universally applicable (see Park, Russell and Lee 2007), Kuznets curves have become a simple but powerful method for empirically testing hypotheses about transitional states.

Smith (1990) proposed an environmental risk transition where the environmental factors leading to ill health were categorized as traditional or modern. This categorization is based on the premise that the major environmental causes of traditional diseases are problems at the household level (e.g., water, sanitation, food availability and quality, ventilation and indoor air pollution). As these are addressed during development there is an increase in the relative importance of the major environmental causes of more modern diseases which operate at the community level (i.e., urban air quality, occupational hazards, toxic chemicals, and motorization). As these are addressed in richer societies a further transition occurs to increase the importance of environmental hazards at the global level (e.g., global warming, land-use change) (Holdren and Smith 2000, McGranahan *et al.* 2000, Smith and Akbar 2003).

Figure 1 shows the environmental risk transition framework in which traditional risks fall with social and economic development, transitional risks rise and then fall, and modern risks rise throughout the development process. Smith and Ezzati (2005) write that limited or no research has attempted to apply this framework to emerging and reemerging infectious diseases caused by evolving human activities such as those associated with trade, tourism, terrorism, and human interactions with natural environments.

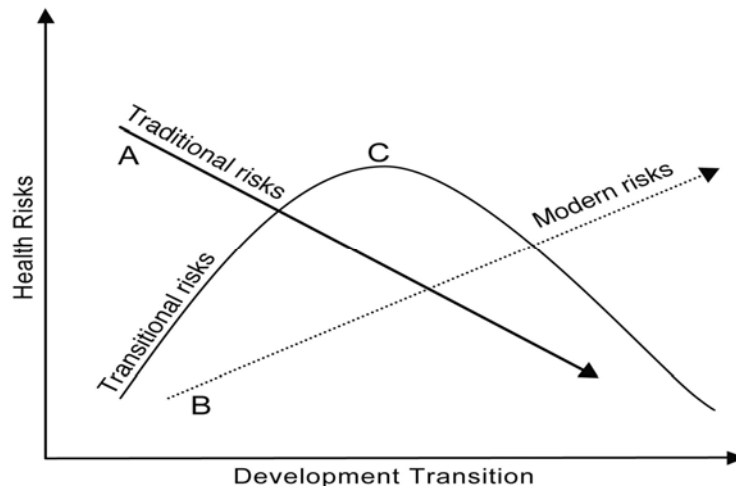


Fig. 1. Environmental risk transition framework

Others have hypothesized forest (a natural habitat) (Mather 1992, 2007; Grainger 1995, Rudel 1998), agrarian (Hall 2004, Rigg 2005), and urban (Douglass 2000, Friedmann 2005) transitions. A forest transition occurs when an initial surge in economic activity spurs deforestation, but as economic activity continues to intensify and cities grow larger, a 'turnaround' occurs, and deforestation gives way to reforestation. The agrarian transition has been defined as a number of inter-related phenomena. These include agricultural extensification and intensification (the amount of agricultural land is hypothesized to follow a Kuznets curve as extensification precedes intensification, but intensification then leads to the abandonment of marginal land);

increased integration of production into market-based systems of exchange; heightened mobility of populations both within and across national borders as people are attracted to opportunities both within and outside of the agricultural sector; and processes of environmental change that reflect new human impacts and new valuations of resources (Akram-Lodhi 2004, deKonick 2004, ChATSEA 2008). The urbanization transition includes two parallel processes: population concentration (population is hypothesized to increase linearly) and the development of socio-physical infrastructure to manage the inevitable conflicts and problems associated with higher density living (infrastructure is hypothesized to increase linearly). The urban transition in developing countries describes societies that have rapidly changed from rural to urban forms of social and physical organization in relatively short time periods (Douglass 2000, Montgomery *et al.* 2004) such as those found in Southeast Asia.

The broader implications of these simultaneous and related transitions remain unexplored in general, and more specifically, as Wilcox and Colwell (2005: 6) argue, in relation to how they produce feedbacks that affect natural communities and ultimately their pathogens, animal host, and human populations. A better understanding of the relationship between development transitions and EID is critical for improving our ability to predict and respond to EID. This is particularly true in Vietnam where government policies have facilitated what can broadly be called a “transition to the market” (deVylder 1990, Fforde 1996, Arkadie and Mallon 2003). Economic policies have driven changes in the built environment that have created new ecological health risks (Oliveira *et al.* 2004, Smith 1997), migration to cities has simultaneously uprooted residents from local social networks and placed them into new neighborhood associations, water user-groups, and other forms of social organization (Crane 1994, Spencer 2007). These new socio-physical ecologies present new challenges that, in turn, require new forms of social organization and governance, many of which do not yet exist, to provide basic services such as water and sanitation, education, housing, and public health.

Another important element of CNH systems that has received little attention to date in the developing world relates to human perceptions of risk. Researchers have developed tools such as the Social Amplification of Risk Framework (Kasperson *et al.* 2003, Pidgeon *et al.* 2003) to describe and explain the societal processing of risk signals, but tests of such frameworks are rare because of the difficulty in predicting when risk amplification conditions are likely to occur (Frewer *et al.* 2002). A central insight of decision science is that risk responses are based on socially constructed perceptions of risk. That is, risk means different things to different people; it cannot be measured independent of our minds and cultures. People prioritize risks in different ways, depending on their beliefs about the need to try to reduce a risk (Park *et al.* 2007, Hofstede *et al.* 1984, Douglass and Wildavsky 1982). Research conducted in the developed world suggests that perceived risk is related strongly to feelings of control and trust (Slovic 2000). Some authors suggest that people perceive low risk during modernization because they feel they are in control of technology, nature, or society and that regulatory authorities can be trusted (Bauman 1992, Beck 1999, Giddens 1992). Over time, however, perceived risk increases as feelings of control and trust are eroded. Some people will respond swiftly and comprehensively to a risk event and others will respond more slowly, depending on a range of psychological and socio-cultural variables and environmental conditions. However, the relative importance of various elements in CNH systems (i.e., socio-ecological and socio-psychological factors) in determining perceptions of and responses to the risk of EID in rapidly developing societies has not been examined.

A basic assumption motivating our proposed research is that risk management policies need to be derived from a broad-based understanding of how decision makers perceive, explain, and prioritize risk. An analysis of EID risk that focuses only on socio-ecological variables will not reveal the socio-psychological differentiation of individuals who are more or less successful in responding to and managing EID outbreaks. Currently, however, there exists a gap in knowledge about the underlying mechanisms that explain variation in perceptions of the risk of EID and how these perceptions vary with social-ecological transition. Furthermore, most research

on perceived risk has been done in democratic, Western countries, not in a context where there is tight state control of key institutions that interpret and disseminate disease risk information. To further understand how EID risk signals are processed by individuals in the context of CNH systems in Vietnam, we need to examine in depth the processes through which people collect and integrate data from natural and human systems. This work will advance basic knowledge about the complex linkages among ecological, social, and psychological variables that amplify or attenuate the intensity and frequency of EID.

4. Background

4.1 The ecological and social economic underpinnings of HPAI in Vietnam

Vietnam, a nation about the size of Italy or Germany, is the thirteenth most populous country in the world. In 1986, the Government of Vietnam implemented free market reforms known as *Doi Moi* (renovation) which provided private ownership of farms and companies, and encouraged deregulation and foreign investment. Since then the economy of Vietnam has achieved rapid growth in agricultural and industrial production, construction and housing, exports, and foreign investment. Vietnam achieved 8% annual GDP growth from 1990 to 1997 and continued at approximately 7% from 2000 to 2005, making it the world's second-fastest growing economy. Simultaneously, foreign investment grew threefold and domestic savings quintupled. Nevertheless, poverty persists in many parts of the country, particularly in the rural upland areas of the country (Minot *et al.* 2006a and b).

Vietnam's rural livelihoods are predominantly based on agriculture, which is largely characterized by smallholder farming. Crop agriculture, livestock, and aquaculture play important roles in the economy of rural households. Both chickens and water birds are prominent and important in the Vietnamese livestock sector. The agricultural census of 2006 counted a total domestic poultry population of 261 million (192 million chicken and 69 million water birds). Poultry production is more widespread in the north compared to the south, although production in the south tends to be at a larger scale per production unit (Epprecht and Robinson 2007). The country's smallholder farmers typically engage in rice production, and domestic water birds are grazed on paddy fields following harvest. Farmers often trade their poultry at live bird markets which involves mixing and frequent movements of a variety of different live animals. These practices create opportunities for interaction with both infected domestic and wild water birds.

The emergence of the HPAI was first reported in Vietnam at the end of 2003 (Delquigny *et al.* 2004). Three major epidemic waves of HPAI have occurred in poultry, resulting in 45 million birds culled between December 2003 and August 2005, leading to a 0.5 percent reduction in GDP in 2004. As of 2008, a total of 106 confirmed human cases and 52 deaths were recorded (WHO 2008). Vietnam has been one of the countries most affected by HPAI and the country has attempted to control the infection through massive, repeated vaccination campaigns in combination with other control measures (Gilbert *et al.* 2008).

Vietnam is a particularly useful country to examine development transitions and their associated environmental transformations because these processes are occurring both exceptionally rapidly and simultaneously as traditional agricultural lands are converted to intensified commercial farming or reshaped into urban settlements to meet the needs of the growing population attracted to cities for emerging job opportunities (Spencer 2007; Douglass *et al.* 2002). If development transitions do pose new challenges to governance, and in particular environmental health challenges, then one would expect to see more of these types of problems in transitional agricultural or peri-urban areas as distinct from both predominately urban and rural areas.

4.2 Summary of anthropogenic and ecological determinants of HPAI in Southeast Asia

Kapan *et al.* (2006) hypothesized that the on-going process in Southeast Asia of replacing traditional farming methods such as multi-species livestock husbandry with industrial, mass-

production-oriented operations poses significant environmental health risks (e.g., Mallin and Cahoon 2003) due to increases in livestock pools and thus opportunities for disease transmission. Simultaneously, rapid urban and peri-urban development in these countries has often been accompanied by more refuse, standing water, and animals in and around homes that have been correlated with environmental health risks (e.g., Graham *et al.* 2004). With respect to HPAI, expansion of the urban fringe has placed a larger proportion of the human population in contact with formerly dispersed farm environments that include potentially infected poultry and swine populations. Such urban–rural interfaces have been hotspots of other infectious diseases such as leishmaniasis (Oliveira *et al.* 2004).

An array of anthropogenic and ecological studies of the determinants of HPAI in Southeast Asia has supported these hypotheses. Gilbert *et al.* (2006, 2007) showed that the interaction of poultry and particularly domestic duck populations within the rice paddy production system was as an important factor for the maintenance and spread of HPAI virus in Thailand. Pfeiffer *et al.* (2007) showed that rice paddy production intensity and density of domestic chickens and water birds were also associated with a higher risk of HPAI outbreaks in Vietnam, lending support to the rice-duck-chicken hypothesis. The same study showed that increased distance from high density human population areas consistently decreased HPAI risk (Pfeiffer *et al.* 2007). The study finds support for the hypothesis of “the presence of a fairly widespread infection reservoir in Vietnam ..., possibly in domestic and wild water birds” (Pfeiffer *et al.* 2007). Gilbert *et al.* (2008) demonstrated that a few key factors such as human population density, rice cropping intensity, and to some extent poultry density, managed to explain a large proportion of the spatial variation in HPAI disease risk; the same study also notes that considerable variation remained unexplained, and suggests that other factors such as poultry production and marketing systems, agricultural seasonality, the potential for contacts between domestic and wild birds, and climatic and other conditions affecting the persistence of the virus in the environment should be considered. Fang *et al.* (2008) found the minimal distance to the nearest national highway, annual precipitation, and the interaction between minimal distance to the nearest lake and wetland, were important predictive environmental variables for the risk of HPAI in China.

Of particular interest to this study is the claim by Gilbert, Xiao, Wint and Slingenbergh (In Press) that the highest risks of HPAI impact in Southeast Asia are to be expected where extensive and intensive systems of poultry production co-exist. The extensive systems allow virus circulation and persistence; the intensive systems promote disease evolution. A study in Thailand found differences in avian influenza risk rates across scale of operations (Otte *et al.*, 2006), which was attributed to bio-security (waste management) features.

Spencer (2008) sought to establish whether bird deaths followed a Kuznets curve as settlement infrastructure patterns evolved. Vietnam’s 1999 Census of Population and Housing provides counts of households by housing construction materials (traditional/temporary or modern), water supply (stream, rain, well, piped), and sanitation infrastructure (none, pit, composting, flush). Spencer converted each of these 4-category, ranked urbanization measures into four distinct measures of settlement “coherence”. For each coherence measure, greater mixing (i.e. incoherence) of the four categories was set to center on a value of zero, with more “traditional” settlement a mixture dominated by the least sophisticated (e.g. no toilet) of each response category valued at (-1), and the most “modern” settlements a mixture dominated by the most sophisticated (e.g. running water) of each response category valued at (+1). Working at the district level, Spencer plotted these three coherence indices, as well as a composite index combining the three, against the probability that a district in any of Vietnam’s provinces (including cities) had an outbreak of HPAI in 2004 or 2005. Figure 2 shows that a distinct Kuznets relationship exists between settlement coherence and HPAI. In particular, the sanitation coherence index explained over one third of variance in outbreaks (R-square = 0.37, bivariate), and the water supply coherence index explained over half (R-square = 0.56, bivariate). Overall,

the findings suggest that the urban transition is associated with HPAI outbreaks in poultry and may be used as a general predictor of emerging infectious disease risk.

The preliminary findings in Fig. 2 illustrate the potential theoretical contributions of the proposed research. Spencer (2008) tried linear, quadratic, and cubic functions to graph the household infrastructure variable on the probability of outbreak, and found that a quadratic curve explained the data best, and produced the highest R-square value. This suggests that for the urbanization measure, at least those measures centered on water supply and sanitation, the basic function may be a Kuznets curve rather than a linear or a more complex curve. This proposal intends to conduct similar exercises for agricultural change and habitat alteration. We will develop transition indices for agricultural change and habitat alteration, plot them against the probability of HPAI outbreak, and choose the curve that best fits the data. A twice-changing slope as the best fit would suggest a more complex fluctuation of risk between traditional and modern landscapes, and a u-shaped curve would suggest that transitional landscapes are associated with reduced risk.

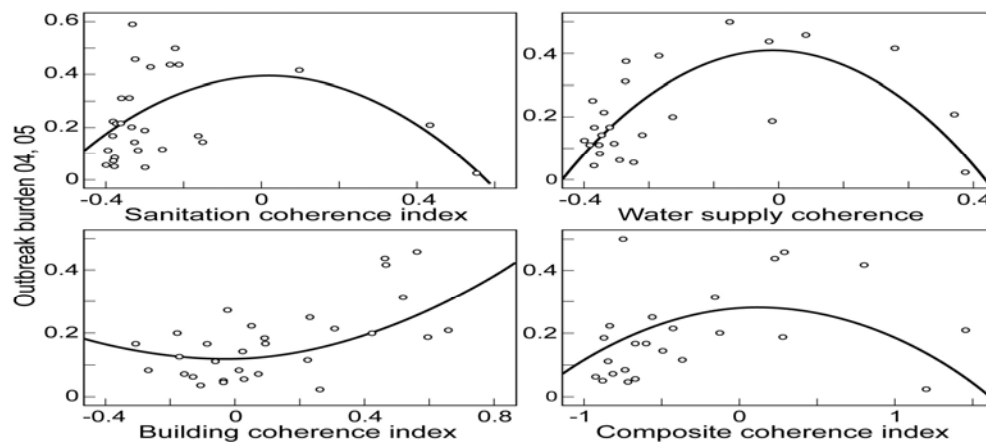


Fig 2. Sanitation, water supply, building, and composite coherence indices

4.3 Empirical studies of perceptions of HPAI risk in poultry and environmental change

Of the few studies that have examined determinants of HPAI risk perceptions, all have focused on perceived risk of HPAI to humans (rather than perceived risk to the health of poultry). Three studies conducted in Asian countries (de Zwart *et al.* 2007, Fielding *et al.* 2005, Figuié and Fournier 2008) showed perceived human risk was correlated with demographics (women and older people perceived more risk) and efficacy (perceived availability of protective actions and ability to engage in those actions led to lower perceived risk). In Laos, Barennes *et al.* (2007) reported that protective behavior was more likely with higher levels of education, urban living, knowledge of HPAI, and owning poultry. Only one of the above studies (Figuié and Fournier 2008) was conducted in Vietnam. No studies have examined the relative importance of socio-ecological variables (urbanization, agricultural change, habitat alteration) versus socio-psychological variables (efficacy, knowledge, affective response, risk avoidance, demographics) in determining perceptions of risk to the health of poultry. Moreover, no studies have examined whether risk perceptions and protective behaviors vary across traditional, transitional, and modern settings or with observed risk (poultry deaths).

5. Research approach and methods

5.1 General framework

The research will follow the framework illustrated in Figure 3. The research will be implemented in two phases and at multiple scales.

5.2 Phase I

Empirical studies on CNH system change and disease emergence depend on the assembly of a diverse set of independently generated neighborhood- and landscape-level data accurately matched with spatially aggregated or ‘point’ level data. In order to make such analyses possible we will develop an extensive spatial database for Vietnam that includes vector layers representing landscape characteristics (e.g., ecoregions, geology, soils, protected area boundaries, human settlements, road infrastructure) from available hardcopy maps, digital data, aerial surveys, global positioning system (GPS) data, and satellite image feature extraction (e.g., urban features (Zhang *et al.* 2002), paddy fields (Xiao *et al.* 2006; 2005). We have already acquired highly synergistic MODIS, Landsat TM/ETM+, and ASTER data and derived products from NASA ESE’s Earth Observing System (NASA 1999), NOAA’s AVHRR (2002), and MERIS data from the ENVISAT satellite (2004/2005). We have acquired orthorectified Landsat images (ca. 1990, 2000) for Vietnam from NASA’s Global Ortho-rectified Dataset. We will obtain GeoCover 13-class (including permanent wetlands) land-cover and land-use (LCLU) maps (30m; ca.1990, 2000) from MDA Federal (formerly Earthsat) for all Vietnam. They will be used as base maps, independent LCLU validation sources, and will deepen our LCLU time-series.

We have also acquired the 1989 and 1999 Vietnam national censuses, and made arrangements to acquire the 2001 and 2006 agricultural census, the 2006 Living Standards Survey, and other economic, demographic, institutional and cultural databases that have been linked to biophysical data via a geographic information system (GIS) (Epprecht and Heinemann 2004; Epprecht and Robinson 2007). This database will also include information on the location and size of villages, roads, streams, and agricultural fields. Any information we collect on specific landscapes through interviews with farmers and key informants in sampled communes will be keyed to this database using handheld GPS devices.

In Phase I we will consolidate and utilize this database to test three models (Fig.3) of the general relationship we hypothesize between HPAI and urbanization, agricultural change (both crop land and poultry), and habitat alteration at the national level using commune level data. The first model (Fig.4, solid lines) will test an *a priori* specific structural equation model (SEM) based on the literature cited above. We hypothesize that outbreaks of HPAI in poultry are associated with variations in three latent constructs: (1) Urbanization, measured in terms of changes in quality of housing and drinking water supplies (Spencer 2008); proximity to cities (Pfeiffer *et al.* 2007) and major roads (Fang *et al.* 2008), and human population (Gilbert *et al.* 2008); (2) Habitat Alteration, measured in terms of changes in wetlands (Gilbert *et al.* 2007, Fang *et al.* 2008), amount and diversity of natural water sources (Fang *et al.* 2008); changes in proximity to wetlands (Fang *et al.* 2008); and (3) Agricultural Change, measured in terms of changes in number and intensity of paddy fields (Gilbert *et al.* 2007, 2008; Pfeiffer *et al.* 2007), and number of ducks and chickens (Gilbert *et al.* 2006, 2007, 2008; Pfeiffer *et al.* 2007).

The second model (Fig.4, dashed lines) tests whether the relations among urbanization, habitat alteration, and agricultural change are attributable to a common higher order influence. While the first model acknowledges the existence of relations among the three latent constructs, it does not explicitly represent cause of covariation. The second model postulates that correlations among the latent constructs can be explained by a higher-order factor. We can thus examine direct and indirect pathways between the latent constructs and HPAI outbreak. The dashed lines in Fig.4 represent the indirect pathways and higher-order factor, which we call CNHS Transition.

Evaluating these models is quantitatively challenging because the concepts of urbanization, agricultural change, and habitat alteration represent a complex multivariate response. Multiple regression analysis of these types of problems are subject to problems of interpretation that include covariances among interacting explanatory variables and an inability to assign unique explanatory capacity to individual factors (Laughlin and Abella 2007; Grace and Bollen 2005). To avoid these problems, we propose to use structural equation modeling (SEM) to test our hypotheses. SEM allows researchers to theorize about why explanatory variables are

Data and Work Flow Diagram

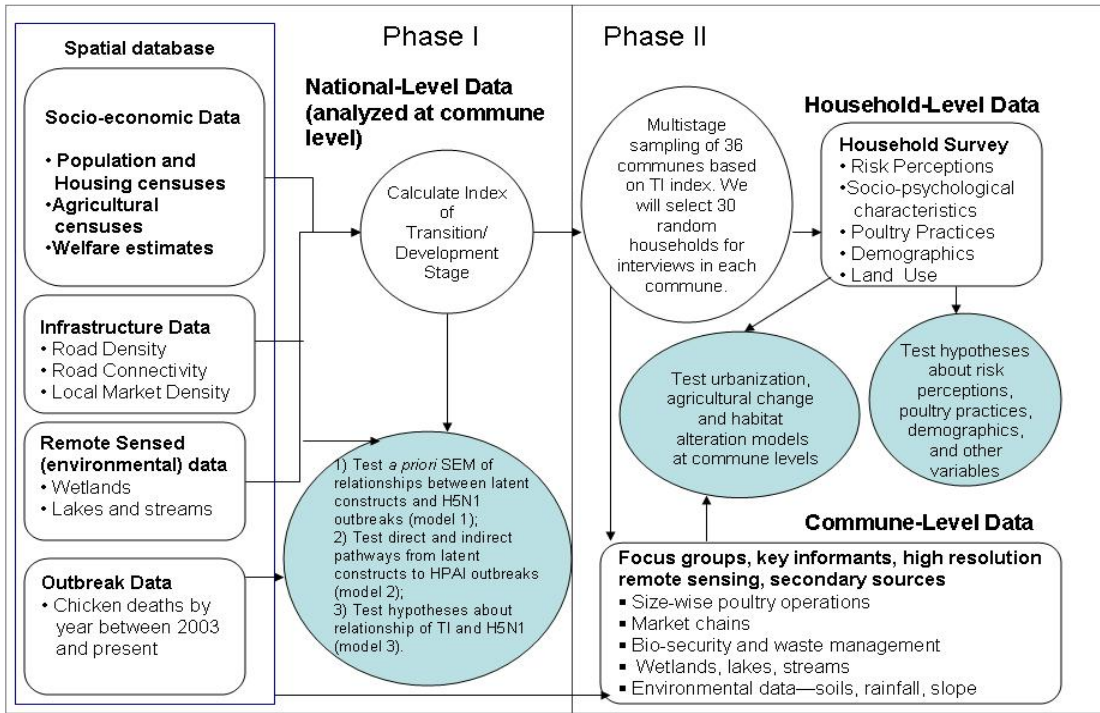


Fig 3. Framework of proposed research to be implemented in two phases and multiple scales

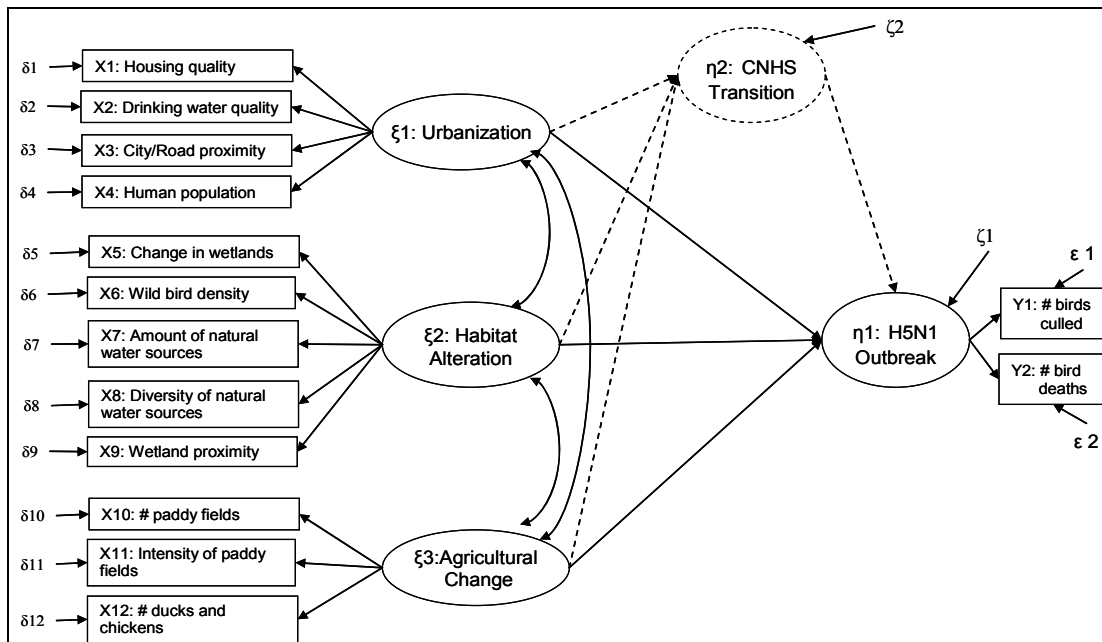


Fig.4. Phase I: SEM models of hypothesized relationships between HPAI outbreak and urbanization, habitat alteration, and agricultural change (both crop land and poultry) at the national level. Model 1 (solid lines) proposes an *a priori* SEM based on existing literature; model 2 (dashed lines) proposes an explanatory higher-order factor.

correlated and to build directional relationships into their models of systems. Explanatory variables are often correlated because they have a common cause or because one factor influences the other (Laughlin and Abela 2007; Shipley 2000). These situations are common in observation studies of complex systems. Consequently we chose to use a systems approach to the analysis and interpretation of composition in this CNH system where driving forces interact to produce observed patterns of bird deaths across the landscape.

In addition to testing two structural equation models, we will use the measures of Urbanization, Habitat Alteration, and Agricultural Change to develop transition indices (TIs) and test the link between these TIs and HPAI (model 3 in Fig. 3). In Spencer (2008) we demonstrated that we could construct a TI of urbanization at the district level. Similarly, in the proposed work, we will construct one TI based on changes in measures of urbanization, a second TI based on changes in measures of habitat status, and a third TI based on changes in measures of agricultural intensity. Each index will be centered on a value of “0” to represent the incoherent or transition state, with values between 0 and 1 assigned to states hypothesized to be increasingly more modern and values between 0 and -1 assigned to states hypothesized to be increasingly more traditional. We will then test the relationship between each TI and bird deaths from HPAI in Vietnam. Finally, we will create one overall TI, based on values from the urbanization, habitat alteration, and agricultural change TIs, weighted according to their internal reliability (determined via factor analysis).

5.3 Phase II

Once we have explored the relationship between HPAI and urbanization, agricultural change, and habitat alteration at the national level, we will examine whether this relationship exists at commune and household scales using focus groups, interviews, and a structured household survey. This is necessary because as numerous researchers have shown, complexity is scale sensitive (Fox 1992, Phillips 1999, Walsh *et al.* 1999). Processes that operate at one scale may not occur at other scales or resolutions.

The Vietnamese government divides the nation into 8 agroecological zones. In order to streamline fieldwork and reduce travel time and expense, in Phase II we will work in the four northern regions: Red River Delta, Northeast, Northwest, and the North Central Coast. This half of the country lies north of Da Nang, and contains 50% of the nation’s provinces (32 of 64) and 52% (344 of 661) of its districts. We will then use multistage sampling to select 9 communes in each of the 4 agroecological zones (3 communes in each transition state as established via the Overall TI in Phase I). We will limit our population to communes in which HPAI has resulted in birds dying.

In each selected commune we will randomly choose 30 households where we will administer a survey to heads of households (1080 total respondents). Informed consent will be obtained from all focus group, interview, and survey participants. We will subcontract scientists at Hanoi University of Agriculture to organize and conduct these interviews and to code the data into a spreadsheet. We will also obtain medium or higher resolution remote sensing imagery (Landsat TM/ETM+, Aster, Ikonos, or Quickbird, depending upon availability for the 36 selected communes) for a more detailed analysis of habitat alterations, and we will use secondary data sources not available at the national level.

We will utilize this sample to test hypotheses (Fig.3, right side) about the relationship between HPAI and urbanization, agricultural change, and habitat alteration using the higher resolution data collected at the commune and household level. We will also test hypotheses about variations in people’s perceptions of the risks of HPAI across traditional, transitional, and modern settings. We will identify alternative protective strategies used by respondents and how these strategies are influenced by ecological, social, and psychological variables.

All Phase II quantitative analyses will be conducted using a type of multiple regression called multilevel modeling (Goldstein 1995, Hox 2002, Raudenbush *et al.* 2002, Singer and

Willett 2003). The name refers to measurements taken on multiple scales. In this phase of our study, there are two levels of data: the commune-level and the household-level. The larger unit is the commune and observations at the household-level are said to be nested within communes. When data are nested in this way, household observations from a given commune are likely to be more similar than household observations across communes. Nesting presents a problem when performing standard multiple regression procedures, because the assumption of independence of observations is violated. When independence of observations cannot be assumed, the estimates of the standard errors are likely to be too small, producing biased results. However, through multilevel modeling, the total variance is partitioned into that from the observation (household) level and that from the larger-unit (commune) level, addressing the problem of underestimated standard errors.

Additionally, at the commune level we will conduct semi-structured focus groups and key informant interviews to gather qualitative information about people's mental models of the relationship between HPAI outbreak, risk responses, and variables that operate on stage of transition (urbanization, agricultural change, habitat alteration). This qualitative work will be conducted in collaboration with the Vietnamese co-investigators, who will assist with translation and conceptualization of key constructs in the local context. The goal of the qualitative work is to tap into diverse perspectives in Vietnam, but the scope of the work will need to be designed to match available resources. Based on the qualitative findings, we will develop items for the household survey.

5.3.1 Urbanization and peri-urbanization

In the second phase of our study we will expand our definition of the urban transition to incorporate characteristics not available in our national-level data sets. Our commune survey will confirm census data on household-level infrastructures (i.e. water supply, sanitation, building materials) in basic counts and will also collect information from household informants on use of these infrastructures and opinions on how they have contributed to public health and sanitation in their daily activities. Additional information will be collected at the household level on residents' daily commute radii, frequency of visits to major urban centers, and changes in social and community-level interactions. During this phase we will also collect commune level data on roads, urban-designated areas, and agriculturally zoned areas. Our hypothesis is that households with intermediate forms of household infrastructure are more likely to be associated with HPAI outbreaks. We also hypothesize that more complex mosaics of urban and agriculturally zoned areas, and greater daily access to urban centers and markets are independently associated with higher HPAI outbreaks.

5.3.2 Agricultural change and habitat alteration

We will test a commune scale model of the coupled agriculture-aquaculture-wetland habitat system (Fig. 5) to examine hypotheses about how various agricultural and natural habitat resources are related to HPAI. Specifically, these variables are paddy production (Gilbert *et al.* 2007, Gilbert *et al.* 2008, Pfeiffer *et al.* 2007), aquaculture (Pfeiffer *et al.* 2007), wild and domestic water birds (Gilbert *et al.* 2007, Gilbert *et al.* 2008, Pfeiffer *et al.* 2007), extent and distance to wetlands (Gilbert *et al.* 2007 and Fang *et al.* 2008), and annual precipitation (Fang *et al.* 2008). Interactions have been observed and/or hypothesized amongst these water related variables and between them and other agricultural and habitat related factors. However, there is a knowledge gap about specific causal mechanisms that can explain the central role of water and how these mechanisms vary across communities in various stages of development. An improved understanding of these causal mechanisms, across transitions, will help fine-tune policies that can prevent future outbreaks of avian influenza.

We hypothesize that at the commune and household level outbreaks of HPAI can be modeled as a function of four constructs representing a well defined coupling of natural and

human factors: extent of water bodies, water contamination (through livestock wastes), density of farms and households, and the domestic import and export of poultry (Fig.5).

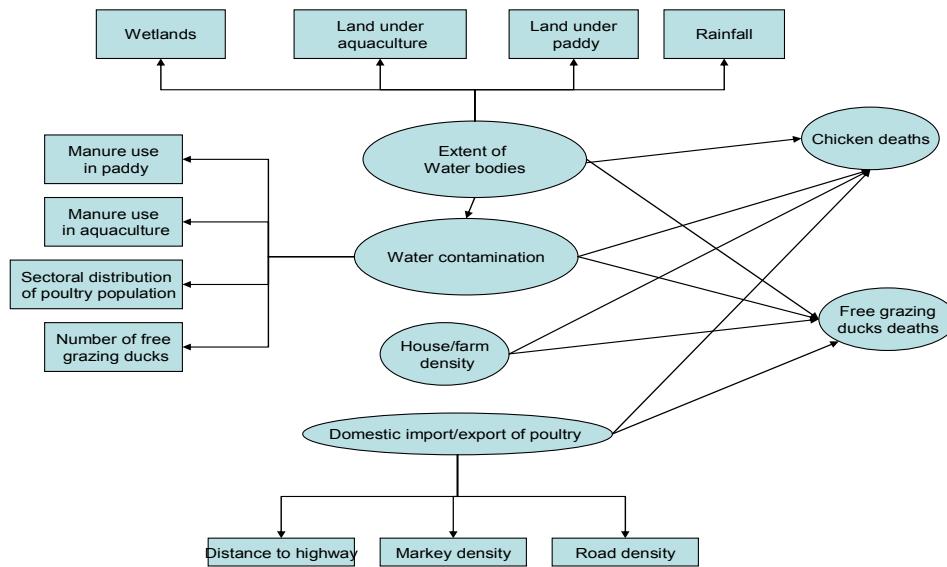


Fig.5: Model of coupled agriculture- aquaculture-wetland habitat system and the impact of livestock wastes

5.3.3 Perceptions of risk and ecological, social and psychological variables

We will examine hypotheses about how the perceived risk of HPAI in poultry varies with multiple socio-ecological, socio-psychological variables, demographics, and outbreaks (all variables are operationalized below). The socio-ecological variables will include the measures of urbanization and peri-urbanization, agricultural change, and habitat alteration being collected at the local level (i.e., population density, infrastructure type and diversity, road density and connectivity, daily commute, social relationships and capital, industrial economic activities, market density and urban designation, extent of water bodies, poultry raising and manure management practices, housing and farm density, and import/export of poultry into commune). The socio-psychological variables (efficacy, knowledge, affective responses, worldviews and trust, demographics) include measures identified in previous literature as important determinants of perceived health and environmental risks.

We hypothesize that perceived risk of HPAI in poultry will be correlated positively (though not perfectly) with observed risk (poultry deaths). We also expect that perceived risk will be higher among individuals in transitional than other settings. We further hypothesize that a significant amount of variance in risk perceptions can be accounted for by socio-ecological and socio-psychological factors. We will examine whether the relative importance of outbreaks, socio-ecological factors, and socio-psychological factors in explaining risk perceptions varies across traditional, transitional, and modern settings. Finally, we will examine the extent to which protective behaviors vary across traditional, transitional, and modern settings.

To analyze the relationship between perceptions of risk of HPAI in poultry and outbreaks, ecological, social and psychological variables (Fig.3) we will construct two hierarchical multilevel regressions that identify determinants of perceived risk for each of three settings (traditional, transitional, and modern). Primarily, we are interested in (a) how much total variance in perceived risk can be accounted for by outbreaks, socio-ecological factors, and socio-psychological factors and (b) the relative importance of outbreaks, socio-ecological factors, and

socio-psychological factors in determining perceived risk. The dependent variable will be created for each respondent by summing the worry and perceived risk scores. To determine the total variance accounted for by the outbreak, socio-ecological, and socio-psychological variables, we will enter all variables simultaneously in the first step of the multilevel regression analysis and examine R-squared. To determine the amount of variance accounted for by outbreaks versus each of the other groups of variables (socio-ecological and socio-psychological), we will first enter the outbreak measures in Step 1 and examine the change in R-squared when the socio-ecological variables are entered in Step 2 and the socio-psychological variables are entered in Step 3. Conversely, we will compare the change in R-squared when the socio-psychological variables are entered in Step 2, followed by the socio-ecological variables in Step 3. We will compare the total R-squared and changes in R-squared in the models constructed for respondents from traditional, transitional, and modern settings.

Additional analyses will examine partial correlations between perceived risk, protective behaviors, and the TIs. Finally, we will examine whether self-reports of the relative importance of several different kinds of information (media, health officials, landscape changes, personal characteristics) varies across traditional, transitional, and modern settings.

5.3.4 Data: Commune and household level

5.3.4.1 Items measuring urbanization and peri-urbanization will include:

Population Density will be calculated as the number of individuals per farm, as well as the number of individuals per commune, and the number of individuals per square kilometer. Farm and local-level population densities and average household size are important aspects of the urbanization construct.

Infrastructure Type will be measured through survey questions on variables such as water sources, types of toilets and other sanitation infrastructure, electricity and other conveniences of urban living. The urbanization hypothesis of disease emergence focuses on simultaneous denser settlement without appropriate levels of household infrastructure. Such transitional, urbanizing areas are often referred to as “peri-urban.”

Infrastructure Diversity will be measured through questions on variables such as diversity of infrastructure, i.e., the mix of running water, well water and other sources, where no one system yet dominates.

Road Density and Road Connectivity will be measured as the internal density of roads within local level areas and the density of connective roads with other local level areas.

Daily Commute will be measured by estimating the frequency of household trips to urban centers and markets, as well as how far they regularly travel.

Social Relationships and Capital will be measured by participation in agricultural collectives, mass organizations (Agricultural Union, Youth Union, Women’s Union), as well as direct questions on participation in community organizations, collective activities, and local leadership efforts.

Industrial Economic Activities will be measured as the percentage of the local workforce engaged in agriculture (including forestry and fisheries). We hypothesize that peri-urban areas will fall in the center of the distribution, with between 40% and 60% of the workforce in agriculture.

Market Density and Urban Designation will be measured by determining what level of government has distinct responsibilities for providing some local infrastructure such as a market, roads, and other infrastructure to facilitate urban ways of living. This administrative characteristic can be included as a dummy variable in our construct of urbanization.

5.3.4.2 Items measuring agricultural change and habitat alteration will include:

Extent of water bodies both agricultural (paddy and aquaculture) and natural (wetlands and rainfall) will be measured using high resolution satellite imagery (if available) or by interpreting medium resolution (Landsat TM/ETM+ or Aster) imagery from different years to

capture both extent and rate of change. If high resolution images are available, we will conduct visual interpretation to adequately identify water bodies. Visual interpretation of this imagery will ensure that the small water bodies used in aquaculture, which may make up a large part of water bodies at the commune level, will be captured. If only medium resolution imagery is available, we will use thresholding of near-infrared and medium infrared bands to automatically extract water bodies. It is noteworthy that in Vietnam, between 1999 and 2004, annual aquaculture growth rates were 31% for production and 19% for culture area (Nhan *et al.* 2007).

Poultry raising and manure management practices will be assessed through interviews with focus groups, key informants, and individuals. We believe that the use of poultry manure (infested with virus) in paddy and aquaculture is likely to contaminate water bodies. When poultry litter is not used for manure or fish feed it is disposed of on land (Burkholder *et al.* 2007 and Otte *et al.* 2006). Rain runoff carries this waste into rivers, streams, ponds, wetlands and paddy fields.

Housing and farm density will be measured from census and other secondary sources. Apart from commune scale movement of wastes across water bodies, there is also the mechanism of direct infection between adjacent flocks. This will happen through inhalation of virus-laden aerosols, for example (Otte *et al.* 2006). We will use farm density as a proxy measure for direct infection mechanisms.

Domestic import/ export of poultry into commune will be assessed by measuring distances to major highway, road densities, and market densities in each commune. Active trading in poultry will increase the chances of infected poultry passing on the virus to susceptible poultry through direct contact (poultry - poultry and poultry- human - poultry) and indirect mechanisms (wastes). We believe that better public infrastructure will be correlated with higher levels of trading, import and export – between communes and between communes and markets.

5.3.4.3 Items measuring perceived risk and related socio-psychological constructs will include:

Perceived risk will be measured in two ways. First, we will ask people to rate worry about poultry in their commune becoming infected with HPAI, using a 5-point scale from “very little worry” to “very high worry.” Second, we will multiply responses on measures of seriousness (scale 1-5) and vulnerability (scale 1-5) and then take the square root to yield a perceived risk scale from 1 (low) to 5 (high).

Protective behaviors will be measured using several yes/no questions that indicate whether respondents endorse actions that protect poultry from HPAI (e.g., administering vaccines, culling sick birds, restricting the use of poultry manure in paddy and aquaculture). One Protective Behaviors score will be created for each respondent by summing affirmative responses on the questions.

Efficacy will be measured via three 5-point scales asking respondents to indicate: (1) belief that a vaccine for poultry is readily available, (2) confidence in the effectiveness of the vaccine if it were available, (3) ability of poultry owners to secure and administer the vaccine. One Efficacy score will be created for each respondent by summing responses on the three scales.

Knowledge will be measured using six true/false items based on questions by Abbate (2006) such as “HPAI is transmitted by saliva, nasal secretions, feces, and fomites of infected birds” and “HPAI in poultry can be prevented by a vaccine.” One Knowledge score will be created for each respondent by summing responses on the six items.

Affective Response will be measured using four 5-point scales asking respondents to indicate likely affective responses if HPAI were found in a household’s poultry: (1) stigma experienced by family, (2) worry about inability to sell poultry, (3) fear of culling, (4) worry about humans getting sick. One Affective Response score will be created for each respondent by summing responses on the four scales.

Worldviews and trust will be measured using 6 items adapted from Dake (1991), Frewer *et al.* (2002), and Finucane *et al.* (2000). For instance, respondents will be asked to indicate their agreement on a 4-point scale with an individualistic worldview reflected in a statement such as

“People with more ability should earn more” or trust of information reflected in a statement such as “Health officials can be trusted to properly manage HPAI risk.”

Importance of information. We will ask respondents to indicate the importance (5-point scale) of each of several different kinds of information when judging the risk of HPAI to household poultry, including: media reports, information from health officials, landscape changes (illustrated with urbanization, agricultural change, habitat alteration variables), and personal characteristics (i.e., self-efficacy, knowledge, affective response, worldviews).

5.3.4.4 Items measuring outbreak and household demographics will include:

Household demographics and other characteristics. Additional items in the survey will assess demographics (age, sex, education, income, number of children, ethnicity) and number of poultry and ducks owned.

Outbreaks. The survey will comprise items designed to measure at the household level the number of poultry that died of HPAI each year from 2003 to the present.

6. Education plan

This project is linked directly to several ongoing educational programs at the East-West Center and the University of Hawaii. The East-West Center funds students from the Asia-Pacific region (including the U.S.) to obtain graduate degrees at the University of Hawaii. EWC funded students enrolled in graduate degree programs in Geography, Anthropology, Economics, Urban and Regional Planning, and Natural Resources Management will be invited to participate in the project. More specifically in this CNHS project we have budgeted funding for three EWC graduate students over the three year research period. One student will be in Population Studies Program (under the direction of Dr. Melissa Finucane) and will assist with the collection and analysis of household data. The other student will be in Geography and will assist with the development and analysis of the spatial database (under the direction of Dr. Zhe Li, Spatial Information Specialist at the East-West Center). A third student will be in the Ecology, Evolution, and Conservation Biology (under the direction of Drs. Wilcox and Kapan). We will seek students from Vietnam or other Southeast Asian countries. Such collaborations have proven in the past to contribute to strengthening institutions whose impact on policy formulation is still constrained by limited opportunities for innovative research outside the conventional boundaries of their disciplines.

Co-PI Dr. Bruce Wilcox is the P.I. and Director of the University of Hawaii’s NSF IGERT: Integrating Ecology, Conservation and Pathogen Biology (ECPB). This is a comprehensive graduate research training program in which students and faculty develop transdisciplinary research skills working on large, multidisciplinary team projects. This includes field work aimed at understanding the reciprocal relationship between infectious diseases and ecosystems, and how human induced environmental change affects this dynamic. The ECPB program is designed to train a new cadre of scientists for a dynamic research at the interface of the disciplines of biodiversity conservation, ecology/evolution and emergent phenomena including diseases and invasive species. This is done by linking faculty and graduate students across many natural and social science departments with the goal of instituting a cultural shift in graduate training. ECPB includes an innovative IGERT core course curriculum centered on "Applied evolutionary ecology: biodiversity loss, biological invasion and emerging infectious diseases", IGERT student's training includes a service component and an international training component focused on Southeast Asia. For more information on the ECPB see <http://www2.jabsom.hawaii.edu/igert/>.

In this CNHS project, we have budgeted for three ECPB IGERT Associates who will participate in the training program and in the project for three years. These students will combine their service and international training by accompanying the field teams to: 1) learn locally 'lived' based issues with respect to the social and ecological bases of emerging infectious disease; 2) interact with local partners; and 3) implement protocols along with our research team to collect

natural and socio-economic data ranging from land use and land cover type validation to on-the-ground interviews for understanding risk perception. Together, the ECPB IGERT Faculty, which includes this proposal's PI's, and our existing NSF IGERT Graduate Fellows and Associates (approximately 20), represent an invaluable multidisciplinary community of natural and social researchers that will be drawn upon for this project. An increasing number of post doctoral researchers and undergraduate students are participating in ECPB team projects; if any of them are interested in participating in this project, we will support their participation.

7. Management Plan

The team assembled for this research consists of individuals with proven strong records in research, application, and management in urban planning, land-use and land-cover change, biosecurity and waste management, perceptions of risk and environmental change, ecology, remote sensing and geographical data analysis, and statistical analysis and modeling.

Dr. Jefferson Fox (Principal Investigator), Senior Fellow and Coordinator of Environmental Studies at the East-West Center, will lead the research on habitat alteration and assist with the research on agricultural change. He will oversee the project and coordinate the work with co-investigators in Hawaii and Vietnam.

Dr. Bruce Wilcox (Co-P.I.), Professor in the Department of Tropical Medicine, Medical Microbiology, and Pharmacology at the University of Hawaii Manoa, is P.I. on an NSF funded IGERT Traineeship program in Ecology, Conservation and Pathogen Biology. Dr. Wilcox will supervise the IGERT student associates funded through this grant and work with our Vietnamese counterparts in Hanoi.

Dr. Durrell Kapan (Senior Personnel), Assistant Research Professor in the Center for Conservation Research and Training and Head of the Applied Evolutionary Ecology and Population Unit in the Asia Pacific Institute of Emerging Infectious Disease, John A. Burns School of Medicine, Univ. of Hawaii, will assist Dr. Wilcox in supervising the IGERT student affiliates.

Dr. Tran Duc Vien (Senior Personnel), Rector Hanoi University of Agriculture, will supervise the work of our Vietnamese counterparts and assist Dr. Fox in managing the project. Drs. Tran Duc Vien and Jefferson Fox have worked together on collaborative projects since 1997.

Dr. Nguyen Huu Nam (Senior Personnel), Dean of Veterinary Medicine Faculty, Hanoi University of Agriculture, will supervise the 10 Vietnamese enumerators hired to conduct by Hanoi University of Agriculture to conduct the household survey in 1080 households.

Dr. Ngyuen Thi Lan (Senior Personnel), Lecturer, Hanoi University of Agriculture, will assist Dr. Nguyen Nam in supervising the enumerators.

Dr. Jim Spencer (Co-P.I.), Associate Professor in Urban and Regional Planning and Director of Globalization Research Center at the University of Hawaii Manoa, will lead the research on urbanization and peri-urbanization.

Dr. Sumeet Saksena (Co-PI.), Fellow at the East-West Center, will lead the research on agricultural change.

Dr. Melissa Finucane (Co-P.I.), Senior Fellow at the East-West Center, will lead the research on perceptions of and responses to risk. She will also supervise the management and analysis of the household survey data in collaboration with Dr. Ian Pagano.

Dr. Ian Pagano (Senior Personnel), Biostatistician in Cancer Research Center at the University of Hawaii, will advise on and lead the quantitative analysis conducted during the project.

Dr. Zhe Li (Senior Personnel), Spatial Technology Specialist at the East-West Center will manage the spatial database, manage and analyze remotely sensed images, and lead the analysis of spatial data. He will collaborate with Drs. Finucane and Pagano on managing/incorporating the household data into the overall database (see supplementary document on data management)

Dr. Michael Epprecht (Senior Personnel), Research Scientist, Swiss National Center of Competence in Research, is based on Hanoi. He will lead the collection, management, and analysis of spatial datasets in Vietnam. He will coordinate with Drs. Fox and Li. Scientists and students from the East-West Center, the University of Hawaii, and Hanoi University of Agriculture will participate in the project. More than ten staff members, including research scientists and graduate students will be training in data collection and analysis methods.

The Honolulu based members will gather monthly at face-to-face meetings to discuss project activities. We will also arrange monthly teleconferences using popular webcasting means to include Vietnam and Asia based team members. At the beginning, middle and end of the project we will hold meetings in Hanoi where all members will participate in the design of project activities, discuss problems and findings, and work toward preparation of final publications.

8. Expected Project Significance

8.1. Intellectual Merit

The proposed program of activities responds to the need for developing basic principles and methods for understanding the mechanisms that underlie new and reemerging infectious diseases (EID) and involve complex interactions within and among natural and human systems. The work will add to the fundamental knowledge base of several interdisciplinary fields, including geography, ecology, systems theory, environmental science, and risk perception. The outputs will enhance the capabilities of researchers, diverse decision makers, and policy makers at local, national, and regional levels. A multi-disciplinary team has been assembled to approach the objectives in a way that has not been attempted before. The major products of the proposed work will include peer-reviewed papers, databases, a household survey instrument translated into Vietnamese, and educational opportunities for graduate students to engage with an international and interdisciplinary team doing research in a developing country.

The project is structured to allow participants to learn from each other's experiences and to develop a more realistic understanding of the challenges and opportunities involved in developing an integrative theory of coupled natural-human ecosystems. Project activities are designed to enhance the knowledge of the scientific community regarding the dynamic coupling between human societies and their ecosystems at scales that range from the local to district, national, and global. The project will further our understanding of the roles of spatial information technology and modeling for understanding long-term processes of ecological change and health risks. Finally, whereas the notion of equilibrium used to dominate thinking about environmental change, this project is based on a non-equilibrium paradigm. Hence the project will further our understanding of development transitions as part of the coupled human-environment system interaction.

8.2 Broader Impacts

The international research team will make an important first step towards building local capacity to study an important problem in a developing world context. A unique research partnership will be formed spanning US and Vietnamese research institutions and a variety of physical and social contexts. We expect that the activities will inform responses to real-world problems about EID. Importantly, since this work will be conducted in conjunction with the end users of the information produced (researchers, policymakers, and poultry owners) we expect the uptake of the information to be rapid and meaningful. Information dissemination resources of the EWC will be used extensively to inform larger audiences of the outcomes.

The project has already established a web site where the proposal, background readings, and related materials and links can be found at: www.eastwestcenter.org/cnhs-hpai-vietnam. The project will produce both integrative publications and articles of more disciplinary focus of research results by the collaborating scientists, both jointly and individually. Dissemination of

research results will be facilitated by the experience and established infrastructure of the East-West Center with long-established links in Asia. Research findings will be presented both at local seminars in the region involving the scientific and development community as well as at international fora.

9. Results from Prior NSF Support

9.1 Dr. Fox was PI of the project ‘Understanding Dynamic Resource Management Systems and Land Cover Transitions in Montane Mainland Southeast Asia’ (Award no BCS-0434043; Amount \$550,000; Support period 09/15/04- 8/31/08). The project involved a multidisciplinary team, including economists, foresters, geographers, and sociologists, to collect economic, demographic, institutional and cultural data that explained how land-use practices are impacted by events such as changes in national taxation policies or changes in roads and markets. The project enhanced the knowledge of the scientific community regarding the dynamics and agents of land use change in Southeast Asia, traced back the impact of these changes on people’s daily lives and their environment, and became the foundation for a long-term longitudinal study of land-cover and land-use change in a region undergoing dramatic social, economic, political, and landscape change. The project was comparative and involves projects from Thailand, Laos, and China. Papers and publications based on this project include:

- Benchaphun Ekasingh, Kuson Tong Ngam, Tanya Promburom, Supakit Sinchaikul and Naruemon Thinrach. 2005. Production systems and land use productivity of farmers in Chiang Mai, Chiang Rai and Lamphun. *Journal of Agricultural Economics* 24 (2): 49-69.
- Fox, J. (forthcoming). The production of forests: Tree cover transitions in Northern Thailand, Northern Laos, and Southern China. In Hecht, S., K. Morrison, and C. Padoch (Eds.). *The Social Life of Forests*. Chicago: University of Chicago Press.
- Fujita, Y. and K. Phanvilay. 2008. Land and forest allocation in Lao People’s Democratic Republic: Comparison of case studies from community-based natural resource management research. *Society and Natural Resources* 21 (2): 120-133.
- Fujita, Y., S. Thongmanivong, T. Vongvisouk, K. Phanvilay, H. Chanthavong. 2007. Dynamic Land Use Change in Sing District, Luang Namtha Province, Lao PDR. Unpublished report for International Program for Research on the Interactions between Population, Development, and the Environment (PRIPODE). Vientiane: Faculty of Forestry, National University of Laos.
- Lebel, L. (2006) Multi-level scenarios for exploring alternative futures for upper tributary watersheds in Mainland Southeast Asia. *Mountain Research and Development* 26 (3), 263-273.
- Phanvilay, K. (forthcoming). Impacts of land-use and land-cover transitions on people’s livelihoods in the uplands of Northern Laos: Case Studies from Bokeo and Louang Namtha Provinces. PhD diss., University of Hawaii, Manoa.
- Thomas, D. 2005. *Developing Watershed Management Organizations in Pilot Sub-Basins of the Ping River Basin*. Bangkok, Thailand: Office of Natural Resources and Environmental Policy and Planning, Ministry of Natural Resources and Environment.
- Thomas, D., B. Ekasingh, M. Ekasingh, L. Lebel, H. Ha, L. Ediger, S. Thongmanivong, J. Xu, C. Sangchyoswat, Y. Nyberg. 2008. *Comparative assessment of resource and market access of the poor in upland zones of the Greater Mekong Region*. Chiang Mai, Thailand: World Agroforestry Center.

9.2 Dr. Fox was PI of the project ‘Spatial Information Technology and Society: Ethics, Values, and Practice’ (Award No. 0221912; Amount \$118,142; Support period 9/1/02 -3/31/05). This project is not related to the current project. J. Fox organized a workshop and follow on case studies to assess ethical, organizational, and socio-economic issues involved in using spatial

information technology for promoting community-based resource management in the Asia/Pacific region. Papers and publications based on this project include:

- Fox, J., K. Suryanata, P. Hershock, and A. Pramono. 2008. Mapping boundaries, Shifting Power: The social-ethical dimensions of participatory mapping. In M. Goodman, M. Boykoff, K. Evered (eds.) *Contentious Geographies: Environmental Knowledge, Meaning, Scale*. Hampshire, England: Ashgate Publishing Ltd.
- Fox, J., P. Herschock, K. Suryanata, and A. Pramono. 2007. Socio-ethical dimensions of spatial information technology. *GIS Development* 11 (8): 34-36.
- Fox, J., K. Suryanata, and P. Hershock (editors). 2005. *Mapping Communities: Ethics, Values, Practice*. Honolulu: East-West Center.
- Fox, J., K. Suryanata, P. Hershock, and A. Pramono. 2005. Mapping Power: Ironic effects of spatial information technology. In J. Fox, K. Suryanata, and P. Hershock (Eds.). *Mapping Communities: Ethics, Values, Practice*. Honolulu: East-West Center.

9.3 Dr Finucane was PI of the project ‘Aging and Disease Recognition’ (award No. SBE–0525238; Amount \$125,000; Support Period 07/01/05–02/29/08). This project is not related to the current proposal and so is described only briefly. In a series of experiments, we examined age differences in judgment processes related to disease and illness recognition. A multiple-cue probability learning paradigm was used to examine younger versus older adults’ comprehension, consistency, and insight on a task requiring judgments of individuals’ health status. Cues about the individuals being judged were directly or inversely related to health status; older adults’ reduced working memory capacity was related to performance decrements (relative to the performance of younger adults) for the inverse relation condition. Papers and publications based on this project include:

- Finucane, M.L. (2008). "Emotion, Affect, and Risk Communication with Older Adults: Challenges and Opportunities", *Journal of Risk Research*, in press.
- Finucane, M.L. & McMullen, C.K., (2008). "Making Diabetes Self-Management Education Culturally Relevant for Filipino Americans in Hawaii", *The Diabetes Educator*, in press.
- Finucane, M.L., Williams, A.E., & Cowan, R.B. (2008). "Older Adults' Multiple-Cue Probability Learning: The Impact of Inverse Cue-Criterion Relations." Under review.

9.4 Drs. Saksena and Finucane were co-PIs of the international workshop ‘Near-roadway and on-road exposures to air pollution: risk communication and decision making’ (Award No. OISE-0853586; Amount \$27,635; Support Period 10/16/08–8/31/09). This workshop is not related to the current proposal. Co-organized with the Asian Institute of Technology, the workshop was held in Bangkok, Thailand, November 9-11, 2008. A highly multidisciplinary group of 20 researchers and graduate students from the US, Thailand, Vietnam, The Philippines, Indonesia, and India delivered lectures and engaged in dialogue in breakout and plenary sessions to advance knowledge about the role of personal exposures to air pollution in decision making—both at the level of an individual and at the level of major stakeholder groups. Participants assessed research capacity in specific Asian cities (e.g., Bangkok, Hanoi, Jakarta, Manila), identified regional partners, and delineated parameters for potential projects that will inform real-world risk communication/ management policies. The workshop laid the groundwork for an international research partnership including physical and social scientists from academia and private and government organizations. Publications based on this workshop will include at least one outreach paper describing gaps in knowledge about the role of personal exposure information in decisions about how to protect oneself from pollution risks.