The Mutual Conditioning of Humans and Pathogens: Implications for Integrative Geographical Scholarship

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We highlight an emerging mode of human–environment enquiry that is executed by cross-disciplinary teams, spurs innovation of hybrid methods, and leads to nonintuitive findings relevant beyond disciplinary framings or specific cases. The extension of this approach in health geography is particularly instructive. By focusing on material objects like soils, insects, or sewage, researchers from diverse epistemologies are compelled to translate conceptual models of disease causation, risk, and vulnerability. Humans and pathogens mutually condition one another, a result of continuously changing exposures (settlement and development patterns that modify pathogen and vector ecology) and institutional processes (legal, economic, and organizational contexts in which environments are modified and agents respond to risk). The dynamic interactions of pathogen ecologies and human institutions produce a type of coevolution, as evidenced by three cases we consider: bacteriological and helminth infections from urban wastewater irrigation, West Nile virus and its mosquito vector in the built environment, and Valley Fever and fungal distribution under changing climate and land disturbance. Place-based, contextual exposure pathways are shown to provide only a partial explanation of disease transmission and must be complemented by insights into individual and organizational agents' motivations, logics, and responses. The object in its context holds the key to understanding the intersection between physical and environmental, and human and governance geographies. Interactively identifying and pursuing theoretical and applied challenges in this manner allows researchers to move beyond entrenched subdisciplinary understandings to frame new supradisciplinary questions. Key Words: human–pathogen interaction, institutions, mosquitoes, Valley Fever, wastewater.

Destacamos un emergente modo de investigación humano-ambiental que se ejecuta por equipos interdisciplinarios, alienta la innovación de métodos híbridos y conduce a descubrimientos no intuitivos relevantes, más allá de marcos disciplinarios o de casos específicos. La aplicación de este enfoque en geografía de la salud es particularmente instructivo. Al concentrarse en objetos materiales como suelos, insectos, o alcantarillado, los investigadores provenientes de diversas epistemologías son inducidos a traducir los modelos conceptuales de la causación de la enfermedad, riesgo y vulnerabilidad. Los humanos y los patógenos se condicionan mutuamente, resultado que proviene de cambiar continuamente las exposiciones (patrones de poblamiento y desarrollo que modifican la ecología del patógeno y el vector) y de procesos institucionales (contextos legales, económicos y organizacionales en que los entornos ambientales son modificados y los agentes responden al riesgo). Las dinámicas interacciones de ecologías patogénicas e instituciones humanas producen un tipo de co-evolución, como se evidencia en tres casos que nosotros consideramos: infecciones bacteriológicas y de helmintos derivadas

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de irrigación con aguas residuales urbanas, virus del occidente del Nilo y su mosquito vector en el entorno ambiental construido, y la Fiebre del Valle y la distribución micótica bajo condiciones de cambio climático y perturbaciones de las tierras. Se muestran las rutas de exposiciones contextuales, basadas en lugar, para suministrar solo una explicación parcial de la transmisión de la enfermedad, la cual debe complementarse con el estudio profundo de las motivaciones, lógica y respuesta individual y de los agentes organizacionales. El objeto en su contexto tiene la clave para comprender la intersección entre las geografías física y ambiental, humana y de la gobernaza. De esta manera, identificando interactivamente y persiguiendo retos teóricos y aplicados, los investigadores pueden ir más allá de entendimientos subdisciplinarios arraigados para formular nuevas cuestiones supradisciplinarias. Palabras clave: interacción humano-patogénica, instituciones, mosquitos, Fiebre del Valle, aguas residuales.

Theory and practice in natural and social sciences have tended to develop along classical, disciplinary lines. Focusing on system subcomponents permitted rapid advances in scientific understanding as well as often-dramatic results derived from applied research. In geography, this entailed specialization in topical and conceptual development, innovation with methods, but also, inexorably, narrowing domains of enquiry (Turner 2002). Splintered communities of enquiry remained interconnected through scholarly exchange and publication, now boosted by the Internet. Narrow focus, however, tended to proliferate research communities within subdisciplinary specialist silos (Bierly and Gatrell 2004; Skole 2004). This trend culminated in periodic contestation as disciplinary entrenchedment, official calls for academic transparency, and heightened competition for dwindling resources pitched many scholarly communities into the “science wars,” where critics focused attention on divisions across epistemology and methods (Smith 1992; Schuurman 2009). This contestation, however, also led to the reinterpretation of research agendas and new modes of enquiry (Kwan 2004; Skole 2004; Jones 2005; Menand 2010).

Here we aim to expand on a particular form of scholarship that emerged from such reconciliation—an object-centered and coevolutionary model of human–environment interaction—with emphasis on its particular manifestation in health geography research (schematized in Figure 1). First, we stress enquiry based on cross-disciplinarity of individual researchers combined with interdisciplinarity among teams that enrich both research and practice. This is made possible by focusing on specific objects as influenced by human and natural processes. In the process we emphasize object–context mutual conditioning. Second, with application to health geography, we consider human–pathogen mutual influences and coevolution, not in biological terms, although this does occur over longer time frames, but as the dynamic, coadaptive interaction between pathogen ecologies and human institutions. After situating our conceptual approach, we explore new understandings of how human–pathogen interactions change over time by considering cases from our ongoing research. In the conclusion we draw out implications of this emergent mode of enquiry for geographical scholarship more broadly.

Conceptual Development: The Role of Institutions in Human–Pathogen Coevolution

The opportunities for specializations to converge are born of two simultaneous acknowledgments across the human–environment and health sciences. On the one hand, there is increasing recognition that knowledge systems and practices, however scientifically and medically founded, are deeply influenced by institutional context (Bowker and Star 1999). At the same time, scholars historically stressing the social and historical construction of environmental problems increasingly account for material and environmental factors (Whatmore 2002; Braun 2004; Robbins and Marks 2009). Research into lab practice and professional training has come to stress the differences in categorization, conceptualization, and assignment of causation rooted in cultures of practice. Despite the interdisciplinary nature of environmental and public health management problems, some organizations have come to be dominated by the outlook and methods of specific disciplinary groups. The resulting explanatory habits, systems of classification, and preference of data to confirm or deny claims differ widely (Becher 1989; Braxton and Hargens 1996) among both scientists (Latour 1999) and practitioners (Bowker and Star 1999). Concomitantly, research has come to stress how the material, grounded conditions of investigation and management can impinge
on the way these explanatory habits and categories emerge. We assert, therefore, that the ways in which objects become linked to people—here, sewage to farmers, mosquitoes to homeowners, and soils to range managers—continue to change over time as a result of ongoing iterations between social habits of knowledge and material conditions of research and practice. This view takes seriously the qualities, activities, and material specificities of nonhumans within what are otherwise considered strictly human processes (Mitchell 2002).

We are interested in material objects, mediated institutionally, as fundamental determinants of health and quality of life. The supradisciplinary challenge of health geography as we understand it is that although pathogens lack intention, they clearly produce a set of behaviors by humans, thus producing a human–environment dynamic that changes over time. The risk of human exposure is both a product of networks linking technologies, disease vectors, and pathogens as a result of the system of diagnosis and causal modeling. Understanding the emergence and trajectory of health risks and outcomes is therefore enhanced by the networking of pathogens, environments, and knowledge systems.

For example, spatial epidemiological models, which attempt to capture some of these complexities, assume that the degree and intensity of exposure respond to intrinsic dynamics of disease agents (DeGroote et al. 2008). Human interaction is understood to occur reflexively as mitigation and abatement and only in a secondary fashion through habitat modification. Model chains functionally underpin this understanding: ecological models for genetics and evolution, systems models for interactions, and population models for exposure. Disease ecology models that link pathogens and environment to epidemiology are overwhelmingly statistical (Kolivras and Comrie 2004; Comrie 2007). Some dynamic models exist, for example, with mosquito-borne diseases (Morin and Comrie 2010). Epidemiological models generally do not deal explicitly with ecological complexities and focus instead on pathogens and disease transmission to humans, and they are usually mathematical or compartmental (e.g., susceptible, exposed, infectious, recovered). Human–pathogen coevolution is sufficiently complex that this developing field will require additional applied cross-disciplinary work as outlined here.

Largely absent from spatial epidemiology and public health more broadly are the mechanisms by which
human–pathogen interactions are influenced by institutions, defined here as organized norms and rules that govern the built environment; for example, urban sewage and zoning policy. Instead, institutions and policy are primarily seen as functional determinants of health service delivery (Mays et al. 2006) or outcomes. Methodologically, health and medical geography has focused on the unit area or small area problem (Riva, Gauvin, and Barnett 2007), in which variable spatial delimitations used for data reporting apparently influence health and well-being. Outcome measures and therefore specific reporting delimitations are institutional at root; however, the structural effects of institutions on disease exposures across reporting units remain inadequately explored. A second concern in health geography that only partially speaks to the mediating influence of institutions is the social inequity of access to services and, thereby, outcomes (Curtis and Jones 2008; Kwan 2009). Here, too, interpretations of mutual conditioning among humans, pathogens, and habitat require improved understanding. Epidemics like severe acute respiratory syndrome (SARS) occasionally bring these concerns to light (Keil and Ali 2007).

These problems in current understandings lead to our conceptual proposition that treats institutions as (1) cognitively and materially shaping human exposure to pathogens, (2) creating pathogen niche ecosystems in the built environment, and (3) presenting both enabling and limiting conditions for human–pathogen coevolution in spatial habitat and institutional terms.

**Of Sewage, Mosquitoes, and Spores**

We discuss evidence from three interactions, less as formal case studies than as an integrated set of observations highlighting principles and insights derived from cross-disciplinary, object-focused, coevolutionary framings. First, food crop irrigation using sewage is shown to be institutionally structured by agency perceptions and mandates, individual and collective agents’ decision priorities, the cognitive and spatial terrain of sanitation, and the physical interactions between coliforms and helminthes on the one hand and producers and consumers of food on the other. The specific nature of these interactions strongly influences health and nutrition outcomes. Second, mosquito vectors’ reoccupation of human settlements and the coevolution of their microhabitats and built environments is shown to respond to layered and often contradictory institutional cognitive mapping, with critical implications for West Nile virus and other infectious diseases. Third, climatic variability and anthropogenic land use trajectories are observed to influence the distribution and disturbance of Coccidioides soil fungus spores that cause Valley Fever. Land use policy and practice plus human behaviors interactively influence spore exposure and fungal habitat, which in turn shape disease surveillance and institutional response.

Let us consider case evidence. Sewage farming continues a centuries-long tradition of human excreta used in food production. Two relatively recent (decades-old) changes to the institutional regimes and material flows of urban wastewater—urban agriculture as subject to management and oversight and wastewater treatment technology and infrastructure—have reconfigured human interaction with coliforms and helminthes associated with this practice. There has been a cognitive shift from resource recovery and productive use of water and nutrients (Asano 1988) to health and environmental hazard (Toze 2006), accompanied by the multiplication and specialization of agencies mandated with various aspects of urban planning and management (Scott, Faruqui, and Raschid-Sally 2004). Illustrative of institutional complexity, Hyderabad, India, has an urban development board, a water and wastewater utility, pollution control and environmental protection agencies, parks authorities, separate agriculture and irrigation departments, farmers’ cooperatives, coalitions of the landless, formal and informal produce marketing bodies, and a public health department—all with multiple, often competing, objectives. Institutional (dis-)articulation has meant that the health risks to the general public from bacterial contamination of wastewater-irrigated food are identified with priority, notwithstanding research demonstrating that market wash water and other contamination immediately prior to the sale of produce poses greater risk of coliform transmission to consumers (Drechsel et al. 2010). Rarely have sewage farmers’ own acute skin-contact helminth transmission, organo-toxins and heavy-metal exposures, or gastrointestinal disease burden been prioritized (Ensink et al. 2010). To the contrary, agency personnel see disease as retribution for urban farmers who transgress regulation, progress, and modernity. The second intervention—primary treatment (or secondary where affordable)—has modified not just wastewater quality but also access and ownership of water and nutrients. The Hyderabad utility produces its own fodder using effluent, although not as productively as neighboring farmers who also grow vegetables, rice,
and nonedible crops. Under conditions of scarcity, the capture of water and nutrients by treatment plants and their subsequent commercialized distribution (in Hyderabad for landscaping and parks) have implications for pathogen exposure. Yet similar to the context of many developing countries with chronic background exposure levels and often-compromised immune response, the outcomes for disease burden attributable to advanced treatment in Hyderabad are questionable, to say nothing of the costs per disability-adjusted life years saved, as demonstrated for the Middle East by Fattal, Lampert, and Shuval (2004). Under these conditions, there is no fully prophylactic course of action for gastrointestinal disease. It is impossible to ensure full coverage of more failsafe therapies—oral rehydration for diarrhea and anthelmintic drugs for \textit{Ascaris}, \textit{Trichuris}, and other protozoa. In effect, humans and pathogens must coexist and continue to mutually influence spatial distribution and behaviors.

Integrative health geography research on wastewater and health, urban and periurban microhabitat spatial dynamics, and individual and collective agents' institutional positioning on risks and gains must account for stakeholder perspectives and the material nature of wastewater flows and pathogen exposures. New habitats for human–pathogen interactions result from urban growth—land conversion and settlement, sanitation practices and services, food provisioning, and health care. They also respond to specific dynamics that are place based but generalizable across the urban–periurban gradient as evidenced in Hyderabad (Buechler and Mekala 2005). The urban core is particularly susceptible to progress and modernity conceptions, in terms of both land use and sewerage coverage; farmers and exposures are pushed toward the periphery—downstream along the Musi River—in search of productive assets (land, nutrients, and water) and decreased regulatory oversight of land use and environmental health concerns with food safety. One implication of the focus on food safety is that in Hyderabad, like other locations, wastewater farmers are constrained by the very interests—urban sanitation and public health authorities—who seek to continue dumping waste without remediation. The specific food production niches and practices of urban farming differ from conventional, rural fieldcropping (Freidberg 2001). Safeguarding vegetables on the vine from theft, frequent watering requirements of soils with poor water-holding capacity, and proximity to market outlets often entail seasonal cohabitation by producers in field tents, with markedly different levels and durations of skin contact exposure to helminth ova than would be the case in other production contexts.

The focus on sewage, then, integrates perspectives of water resources geography, microbiology, public health, sociology, and agronomy, among others. Researching the coevolution of human–pathogen interactions in periurban sewage irrigation thus hybridizes spatial and institutional research with practitioners' emphases on measures taken by the utility, public health, and agricultural and irrigation agencies, as well as farmers' production and marketing arrangements. This integrated perspective raises several questions. How does sewage as resource and hazard alter the food security and public health outcomes of urban sanitation? How does urban agriculture's internalization of pathogens influence farmer, consumer, and manager behaviors and how do these mediate gastrointestinal and helminth infections?

Although operating in a very different economic and ecological context, the threat of West Nile virus in the U.S. Southwest, and the analysis of its drivers and risk management, shares several key elements with the previous case. Although southern Arizona and Sonora have long been the center of mosquito-borne insect problems and epidemics (Teeples 1929; Fink 1998), the problem is novel, in historical terms, insofar as the interactions of contemporary system elements driving the central vector—the mosquito—are largely recent. The decline of wetlands and surface-water flow combined with the widespread use of DDT and other chemical controls in the twentieth century to significantly reduce mosquito populations. By 2005, the region had seen the expansion of vector-carrying species of mosquito, including \textit{Culex quinquefasciatus}, many of which are capable of overwintering in the region. These have been found in both wetland and residential areas—occupying built environment niches similar to the wastewater case—and continue to feed extensively on humans and birds, presenting a serious West Nile risk (Zinser, Ramberg, and Willott 2004).

The return of the insect vector is a response, in part, to the institutional logics and patterns of urban development in the region. Urban land development has been especially influential, including increases in backyard habitats like lush landscaping, neglected swimming pools, unmaintained fountains, and abandoned tires. For \textit{quinquefasciatus}, a rise in breeding habitat has further followed the deliberate restoration for amenity and ecosystem services of previously drained wetlands, as well as the construction of wetlands for wastewater treatment (Willott 2004).
The development of the vector threat has simultaneously resulted in the promulgation of control techniques, each of which further reflects divergent assumptions about mosquito behaviors and causes. Adulticiding efforts utilizing methodical aerial spraying in some locations contrast with source-control strategies and larviciding in others (Shaw, Robbins, and Jones 2010). Each such response, and its differential impact on breeding, risk reduction, and disease distribution and evolution, is itself enmeshed in urban development history. Whereas some abatement offices and health departments seek reduction in public complaints, others respond to trap counts and geographic information systems (GIS) data. Landscapers focus on enhancing aesthetics and property values, whereas drainage infrastructure managers seek to minimize flooding. Planning for West Nile thus interacts with divergent incentives and institutional contexts to produce heterogeneous contexts for the disease and its vectors to evolve and adapt. Spatially heterogeneous built environments, dynamic hydrological systems, and shifting control philosophies have enabled the development of the vector in some areas and retarded it in others, with no sign that final resolution to the “mosquito wars” is at hand (Spielman and D’Antonio 2001). In a sense, then, through specific modalities of “mosquito wars” is at hand (Spielman and D’Antonio 2001). In a sense, then, through specific modalities of coexistence in the city, humans and mosquitoes have come to mutually influence one another’s behaviors.

Although conventional spatial analysis can be used to determine important predictive variables (DeGroote et al. 2008), this case shows that emphasis on the mosquito as well as modeling and mapping of disease trajectories depend on the integration of multiple forms of data and characterizing of diverse system elements. Landscape-scale analysis of municipal morphology must be advanced utilizing mosquito-relevant land cover classes. These require integration into vector-population models sensitive to dynamic microscale temperature and precipitation impacts on differing life stages of the insect. These must be integrated with the jurisdictional behaviors of managers and neighborhood-scale practices of diverse publics—a akin to institutional disarticulation for wastewater—that in turn are sensitive to the degree and distributions of disease outbreaks and differing institutional and community knowledges and priorities. Starting from the mosquito as the object of integration, the coadaptation (and coevolution) of vector distributions and mitigation strategies, mediated by a built environment that answers to exogenous political and economic drivers, becomes the central focus of meaningful epidemiological research, which is by its nature interdisciplinary. This raises the need for integrative enquiry on how institutional forms reconfigure human–mosquito interaction. Further research must address this question: Will preferences for specific built environments and managerial mandates perpetuate West Nile virus and produce new mosquito vector-based exposures, especially dengue and malaria?

The third case from our research, *Coccidioides* spp. soil fungi that cause Valley Fever (frequently abbreviated as cocci), are New World in origin and have evolved into two species (Fisher et al. 2001). Their spread from arid North America to Central and South America is thought to have accompanied the migrations of the first humans and their animals. Today, human–c cocci mutual conditioning follows an exposure logic: Modification of the desert environment for human habitation disturbs the pathogen’s soil habitat and heightens host contact with fungal spores. Addressing the primary interactions requires cross-disciplinary approaches to spores, soil, habitats, and inhabitants. Detection of cocci spores in the environment is very poor and therefore so is understanding of key social factors, necessitating a high level of research collaboration across complementary perspectives including medicine, vaccines, cellular and molecular biology, epidemiology, fungal genetics, fungal ecology, soil science, both micro- and landscape-scale ecology and biogeography of specific habitats, remote sensing and GIS, and climatology.

Physical contextual factors such as climate and weather variables (temperature, precipitation, humidity, wind, etc.) and ecology variables (vegetation type, phenology, hosts, vectors, and pathogens in the environment), when combined, are observable only at the landscape scale. Habitat is thus a scale proxy for pathogens (or vectors) that cannot be resolved individually. Observing hosts and their behaviors requires spatial data compromises to work around data unavailability at the pathogen scale; for example, mapping cocci-infected individuals by home address, knowing that the spore exposure might not have occurred at that specific location because of host movement or because of broader scale exposure via wind-blown transmission of the spores from elsewhere, causing exposure at that location. Overt collaborations among the range of researchers previously mentioned, specifically focused on elucidating fungal ecology, have partially overcome the data challenges to explain fungus–environment interactions, as in establishing and confirming key hypotheses regarding the role of climate in interannual disease seasonality and outbreaks (Tamerius and Comrie 2011).
Social and institutional contextual factors are similarly challenging. As with other diseases (Kwan 2009), uneven and changing case reporting for coccidioidomycosis exposure detection leads to significant public health surveillance uncertainties. Physicians seeing patients might not test for cocci or might not report it if identified. Central laboratories perform tests that can change with time, but their clinical data collection priorities do not necessarily align with epidemiological data priorities for public health, let alone environmental science data needs. Coccidioidomycosis incidence is increasing, but given the different institutional perspectives it is not surprising that its cause is contested, whether it be climate, urban expansion and soil disturbance, better reporting, or even whether the trend is real (Tamerius and Comrie 2011). Valley Fever has no cure per se, although antifungal drugs are effective in many cases and there is active work on a vaccine. Adaptive response is therefore the principal public health intervention, but it is difficult for two reasons. First, and most important, cocci spores are effectively ubiquitous; it is impossible to fully treat the environment or protect hosts across multiple environments in which they are active. Second, even if specific cocci source locations were identifiable, it is unknown what sort of soil remediation would be effective, practical, and safe. Thus, humans and pathogens must coexist in mutually conditioned habitats, just as we observed for the wastewater and mosquito cases earlier.

There are both lessons and challenges for health geography scholarship on cocci. Environmental and biological scientists are trying to detect an organism that is effectively invisible on the landscape—this remains the essential challenge. Finding answers to where, when, and how the spores are distributed presently requires an elaborate and expensive process of soil data collection and testing via mice to ascertain whether a sample is positive, with very low detection rates. Pathogen-focused cross-disciplinary collaboration has enabled advances in understanding geographic dimensions of cocci by working through the complex association with coccidioidomycosis. New genetic and molecular techniques offer the opportunity to make further advances by counting cocci directly, an approach currently outside the realm of conventional geographic tools but ripe for new collaborations between geographers and molecular and cellular bioscientists. Approaching the human–cocci challenge from social and institutional perspectives will entail investigation of behaviors that heighten exposure. Seemingly inexorable urban expansion and the institutions that produce it can clearly contract and expand cocci habitat and subsequent exposure, like periurban agriculture and mosquito vector habitats. Assuming that pathogen habitat was well understood, and acknowledging progress with institutionally produced data, the public health dimension will need to evolve from a medical response to unknown environmental and social strategies for mitigation. Cocci exposure, then, is produced via mutual conditioning of humans and pathogens in unique microhabitats and societal contexts, raising questions for continued research: How will improved cocci detection and monitoring inform epidemiological research? Will this translate to diminished Valley Fever incidence? Will economic drivers of open-space development account for the influence of land disturbance on cocci distribution?

Conclusion

The three cases of human–pathogen interaction presented have identified challenges and methods derived from a focus on institutionally mediated physical exposure: sewage-based transmission of gastrointestinal and helminth infection, mosquitoes in produced habitats for West Nile virus, and open-space development coupled with climate variations for Valley Fever. Despite providing diagnostic insights, there are limitations to understanding human–pathogen interaction as primarily place-based exposure. The effect of institutions in framing problems and risks and defining the scope of decision sets to address health challenges needs to be underscored. This requires new theoretical approaches—hybrid at times, clean-slate innovative at others—and new ways of seeing.

Cognitive maps resulting from focusing on physical objects contribute to new understandings of human–pathogen interaction and to coevolutionary effects of objects on researchers and managers. In this article, we have conceptualized this hybrid approach as shown schematically in Figure 1.

New hybrid framings stemming from this approach raise several propositions that are relevant for broader geography scholarship, most saliently:

- The mutual conditioning of objects and humans expands outcome possibilities; for health geography, human–pathogen interactions are bidirectionally causal.
- Object-oriented enquiry bridges multiple epistemologies; geographical research practice is thereby enriched, as presented here for health geography,
but also for water, energy, or other objects of concern occupying the Annals.

- Cross-disciplinary framing of questions and methods leads to fundamentally new understandings; geographers must continue at the forefront of this mode of dialogic enquiry.

In sum, it has long been acknowledged that health geography necessitates interdisciplinary and intersubdisciplinary perspectives (Turner 2002; Kwan 2004). We suggest that such integration is best achieved through an approach that starts from concrete objects, stresses the entanglement of material landscape conditions with knowledge and assumptions, and pursues the coevolutionary development of hazards and the institutions that mediate human interactions with them.

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