EcoHealth 7, 425–438, 2010
DOI: 10.1007/s10393-010-0354-6

EcoHealth

Original Contribution

Climate Change, Vector-borne Disease and Interdisciplinary Research: Social Science Perspectives on an Environment and Health Controversy

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Abstract: Over the last two decades, the science of climate change's theoretical impacts on vector-borne disease has generated controversy related to its methodological validity and relevance to disease control policy. Critical social science analysis, drawing on science and technology studies and the sociology of social movements, demonstrates consistency between this controversy and the theory that climate change is serving as a collective action frame for some health researchers. Within this frame, vector-borne disease data are interpreted as a symptom of climate change, with the need for further interdisiplinary research put forth as the logical and necessary next step. Reaction to this tendency on the part of a handful of vector-borne disease specialists exhibits characteristics of academic boundary work aimed at preserving the integrity of existing disciplinary boundaries. Possible reasons for this conflict include the leadership role for health professionals and disciplines in the envisioned interdiscipline, and disagreements over the appropriate scale of interventions to control vector-borne diseases. Analysis of the competing frames in this controversy also allows identification of excluded voices and themes, such as international political economic explanations for the health problems in question. A logical conclusion of this analysis, therefore, is the need for critical reflection on environment and health research and policy to achieve integration with considerations of global health equity.

Keywords: climate change, vector-borne disease, frame, interdisciplinary, scale, equity

Introduction

Scientific and policy debates over environment and health issues can bring differing vocabularies, worldviews, and values into play. (We employ "environment and health" in this article to denote situations where aspects of the biophysical environment affect human health, in favor of contested terms such as "environmental health" and "ecosystem health.") The December 2008 issue of *EcoHealth*, for example, contains book reviews describing different approaches to understanding and controlling infectious disease, in which each book is reviewed by the other's authors (Keesing and Ostfeld, 2008; Mayer and Pizer, 2008). While the approaches in question originate in different academic traditions, covering biological and social science/epidemiological approaches, the reviewers point out the considerable overlap and complementarity between their approaches, consistent with an "all hands on deck"

Published online: December 2, 2010

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transdisciplinary approach to addressing emerging infectious diseases (Parkes et al., 2005). In this article, in contrast, we examine one particularly acrimonious controversy that illustrates some of the potential obstacles to productive work across disciplines.

Climatic influences on vector-borne diseases (VBDs) have been a subject of intense debate for most of the past 20 years (Taubes, 1997; Tong and Soskolne, 2007), pitting those who hold climate and climate change to be relevant to understanding and controlling VBDs against those who hold them to be irrelevant or of minor importance. A number of commentators on, and participants in, this controversy have offered more-or-less superficial explanations for it. A news story in *Science* (Taubes, 1997) implies that the conflict originates in the reactions of infectious disease specialists to the "doom and gloom" predictions of environmentalists. In a *Lancet* news story on disputes over dengue's relationship to climate change (Barclay, 2008), "environmental scientists" are said to be pitted against "infectious-disease specialists," in spite of the major presence of epidemiologists and physicians in literature linking climate to VBDs. (Jonathan Patz, for example, is described as an "environmental scientist" in the conclusion to Barclay's account, when in fact he is a physician and health researcher.) Chaves and Koenraadt (2010) highlight the role of a "panclimatic paradigm" (p 36) in explaining the controversy over climate change and malaria, presumably alluding to Thomas Kuhn's (1970) work on the role of paradigms in "normal science" and scientific revolutions. In Randolph's (2010) brief exploration of climatic and other influences on tick-borne diseases, the high public profile of climate–VBD research (and her own skepticism towards it) is attributed to repeated publication of a "compelling map" (p 93) of future malaria distribution in peer-reviewed publications in the late 1990s. And Paul Reiter (e.g., 1998c) has repeatedly attributed the controversy to an irresponsible and opportunistic intrusion of politically motivated "rocket scientists" and other environmentalists into the field of VBD epidemiology. In all of these cases, social explanations are offered for the controversy, but in none of them are formal social science methods related to the study of controversies (e.g., Martin et al., 1995) employed. In this article, we interpret the climate–VBD controversy in light of social theories concerning interdiscipline formation, collective action framing, and boundary work, concluding that climate change appears to be serving as a frame within which interdisciplinary research is put forth as the logical consequence of data on VBDs. Based on this finding, we end by calling for further critical reflection on the social aspects of science dealing with health and the environment.

Methodology

The research described in this article employed an evolving methodology that could only be fully described in hindsight. The study began with a graduate student's sense of unease with the extraordinarily heated exchanges observed in peer-reviewed literature on the topic of climate and VBDs, and with the apparent absence of important political considerations from both sides of the debate. A number of approaches were used to explain the polarized positions observed in the debate, beginning with an attempt to understand the "objective" validity of evidence for, and against, the relevance of climate and climate change to VBDs. While helpful, this approach ultimately failed to explain a number of striking features of the controversy, including its distinctive rhetorical content and frequent references to responsible science and the public interest. We thus used social theories and methods drawn from science and technology studies (STS) and the sociology of social movements to provide a fuller explanation for the controversy. The peer-reviewed contributions of four "proponents" and four "opponents" of the validity and importance of climate–VBD science were interpreted using relevant social theories. The use of similar methods to analyze both sides of a controversy is consistent with the "strong program" approach to STS, which adopts an agnostic stance towards questions of who is ultimately right (Martin et al., 1995). The view that scientific knowledge is "socially constructed" (Hannigan, 1995), however, does not necessarily imply that all competing scientific claims are equally valid (McCright and Dunlap, 2003). For the purposes of this article, we deemed it more important to explain the controversy's extra-scientific content than to reach a final scientific verdict.

The choice of social theories used to interpret the controversy relied on the second author's expertise as an environmental health sociologist. The eight scientists in question were chosen based on the first author's familiarity with the scientific literature on climate and VBDs, and experience gained through personal and professional interactions in the climate change and health research and policy communities. While a number of other researchers have expressed their hesitation about climate and VBD research (Taubes, 1997),

the four opponents discussed in this study were chosen for their consistent, longstanding, and sometimes colorful criticism of the methodological validity and public policy relevance of climate–VBD science. David Rogers, Sarah Randolph, and Simon Hay of the Oxford University Department of Zoology have authored numerous papers on the topic, including research exploring the scientific basis for links between climate, insects and ticks, and human illnesses. Paul Reiter, formerly of the U.S. Centers for Disease Control and Prevention and currently with l'Institut Pasteur in Paris, has co-authored publications with Rogers, Randolph, and Hay, has published review papers and critical correspondences on his own, and has spoken out on the topic in various non- peer-reviewed forums.

The four proponents are among the most prolific publishers, and vocal public speakers, in the field of climate change and health. They were chosen for their prominence, as well as for the ways in which their work seemed to demonstrate the themes most criticized in the work of the opponents. Anthony McMichael is an epidemiologist, formerly at the London School of Hygiene and Tropical Medicine (LSHTM) and currently at the Australian National University. He has played a leading role with respect to the human health chapters of the Intergovernmental Panel on Climate Change (IPCC) assessment reports, and has published extensively on the topic of global environmental change and health for decades. Paul Epstein, Jonathan Patz, and Andrew Haines are physician-researchers located at Harvard University, the University of Wisconsin—Madison, and LSHTM, respectively. They have published extensively on climate change and health issues, and play leadership roles in science and policy related to the topic in the US, the UK, and internationally. We recognize that there is a large body of work on climate and VBDs, and that these four are not (or are not exclusively) VBD specialists. Nevertheless, they are certainly central figures in the international literature on climate change and health, one of the key components of which is potential climatic influences on VBDs. In contrast, all four of the opponents discussed in this article can be classified as medical entomologists, or at least VBD specialists (and their climate-related publications are entirely focused on VBDs). It should be emphasized that the social theories and scientists discussed in this study were chosen using professional judgment and not a priori selection criteria. Our analysis is therefore not reproducible or generalizable, but is nevertheless potentially informative to the practice of environment and health research and policymaking.

Peer-reviewed articles by the eight scientists in question were identified for analysis through the first author's immersion in the topic as a graduate student and Canadian federal government employee, as well as using keyword searches with unrestricted date ranges (performed in February 2009) in *Web of Science* using combinations of the keywords "climate," "ENSO," "vector," "tick," "mosquito," "insect," "malaria," "dengue," "lyme," "chagas," "leishmaniasis," and "health." The references of papers identified in this manner were examined for relevant titles, and forward-searches were performed in *Web of Science* to find papers citing identified sources. For the peer-reviewed contributions of the opponents, entire papers were read and passages commenting on the validity and policy relevance of climate–VBD science were highlighted, as well as passages commenting on the competence and alleged biases of scientists carrying out such work. The peer-reviewed contributions of the proponents were also read in their entirety, but text to be analyzed was highlighted only in the introductory and concluding sections. This choice was made because the themes of relevance to interdisciplinary collaboration were most prominent in these sections. The themes of relevance to the proponents were somewhat different than those highlighted for the opponents, focusing on the reality of anthropogenic climate change, the need for interdisciplinary collaboration to address resulting health challenges, and the role of health professions and disciplines in such collaborations. While the publications of the opponents focus exclusively on VBDs, those of the proponents also include more general review papers on climate change and health in which VBDs play a prominent role.

All highlighted passages were coded by theme, with themes suggested in advance by the chosen social theories. Interpretation of the highlighted text employed interpretive thematic analysis (e.g., Browne, 2007), involving consultation with experts to help interpret texts in light of social theory. Experts included the second author, but also anonymous reviewers of earlier drafts of this article submitted to *Social Science & Medicine*, *Social Studies of Science,* and *EcoHealth*, as well as individuals working and studying in the field of climate change and health who were accessed over a period of years by the first author. An additional synthesis step included examining the results of the thematic analysis together with critical reflections on the international political economy of health and the role of ecosystem health researchers vis-à-vis global health equity. The study of texts, in relation to accompanying social practices, is a hallmark of the analytic technique known as

discourse analysis (Ashmore et al., 1995), and the fact that we intended to arrive at more equity-conscious science and policy makes our approach a rudimentary form of *critical* discourse analysis (Fairclough and Wodak, 1997). In that the research was informed by the first author's work as a graduate student in environmental studies and epidemiology, and employment experience working on climate science synthesis and climate change and health files for the Canadian federal government, the methodology could also be described as including a rudimentary form of participant observation (Schensul and LeCompte, 1999).

Results

Vector-borne Diseases, Climate, and Climate Change

The relationships between climatic factors and VBDs (including projected impacts of anthropogenic climate change) are reviewed in the human health chapters of the IPCC assessment reports (IPCC, 1990; McMichael et al., 1996, 2001; Confalonieri et al., 2007), as well as in peer-reviewed articles (e.g., Rogers and Randolph, 2006; Zhang et al., 2008). Evidence pertaining to such links begins with the fact that disease-transmitting invertebrates such as ticks and insects (e.g., mosquitoes, sandflies, and blackflies), as well as rodent populations, are biologically sensitive to climatic parameters such as temperature and precipitation. Beginning in the early 1990s, concern over anthropogenic climate change motivated studies in which statistical relationships were sought between data on climatic parameters and on vector parameters of relevance to risk of disease, often malaria (e.g., Loevinsohn, 1994). A second approach to investigating climate–VBD links involves the construction of process-based or deterministic models of insect and tick behavior, which consist of systems of equations representing best-available biological knowledge regarding a particular vector's sensitivity to climate (e.g., Martens et al., 1995; Ogden et al., 2005). Both statistical and process-based models can, once validated, be loaded with climate parameters obtained from General Circulation Model (GCM) runs to obtain arguably meaningful projections of future disease risk. An important subset of research on climate–VBD links has examined the effects of the El Niño Southern Oscillation, a recurring large-scale climate perturbation that is projected to be affected by anthropogenic climate change (Kovats, 2000).

The range of pathogens studied with respect to possible climatic influences is large, encompassing viral, protozoan, and bacterial infections (among others), and both lower- and middle-income, and high-income country settings. A major focus has been on malaria, with highland regions of Africa especially frequent subjects of study because of the possibility that climate warming will allow malaria's mosquito vector to survive at higher altitudes (Chaves and Koenraadt, 2010). This raises the prospect that immunologically naive populations adjacent to endemic areas will become newly vulnerable, or have already become so. Mosquito-borne viruses such as dengue, West Nile, and yellow fever are another major focus (Reiter, 2010a, b), as are Lyme disease and other tick-borne encephalitides (Randolph, 2010). Lesser-known diseases such as leishmaniasis, schistosomiasis, and rodent-borne diseases such as hantavirus and plague have also been examined in a smaller number of studies. The task of critically appraising, synthesizing, and communicating the results of this large, diverse, and rapidly changing body of knowledge is a difficult one, and most reviews on the topic are hesitant and qualified in their overall assessment of the relationship of climate to VBDs (e.g., Rogers and Randolph, 2006; Confalonieri et al., 2007; Zhang et al., 2008). In the careful language of the IPCC, "climate change has…altered the distribution of some infectious disease vectors (medium confidence)" and will "continue to change the range of some infectious disease vectors (high confidence)" (Confalonieri et al., 2007, p 393).

Interdisciplines, Frames, and Boundary Work

A compelling interpretation of the controversy lying behind such summary statements is provided by work on the formation of "interdisciplines." Using the example of the "genesis" of the discipline of genetic ecotoxicology in the late 1960s and early 1970s, Frickel (2004) demonstrates how scientists reinterpreted existing scientific knowledge concerning environmental exposures and genetic mutations to justify establishment of an interdiscipline, or a hybridized knowledge field combining elements of existing disciplines. Interdisciplines imply institutional conflict (Klein, 1996), and their formation "involves disputes over access to organizational, technical, financial and symbolic resources"; furthermore, their stabilization "reflects a reordering of theoretical loyalties, epistemic assumptions, research practices, standards of evidence, and professional credibility and identity" (Frickel, 2004, p 269).

Traditional disciplines are housed in university departments, and their maturation involves solidifying the boundaries between their purview and methodologies and those of other epistemological approaches (including other academic disciplines) (Turner et al., 2000). This ''boundary work'' accomplishes monopolization of professional authority and resources, excluding rivals by characterizing them as amateurs (Gieryn, 1983, p 792). Boundary work typically employs a rhetorical style attributing specific characteristics to science (e.g., objectivity, impartiality, honesty, rigor), and contrasting it with ''non-science'' (characterized by partiality, hysteria, laziness, dishonesty, etc.). In the case of a specific discipline, all those methodological approaches that are not practiced by its members can be considered non-science when applied to that discipline's subject matter. In interdiscipline formation, however, boundary work is better described as a process of challenging existing disciplinary frontiers (Frickel, 2004). The eventual goal is maintenance of permeable boundaries to allow the use of multiple disciplinary perspectives, often in the context of resolving a specific real-world problem.

Perpetually porous disciplinary boundaries present a less stable and powerful situation than do traditional disciplines, with their well-established institutional backing. In the absence of such support, work within interdisciplines can be motivated by a collective action frame (Frickel, 2004). A collective action frame is an interpretive construct used to make sense of an issue in such a way that social movement participation is encouraged (Snow et al., 1986). Frames are established and buttressed through techniques of frame alignment—essentially tools of persuasion—which convince potential movement participants to join in (Benford and Snow, 2000). Thus, a strongly held belief can inspire researchers to challenge existing disciplinary boundaries and advocate for the establishment and institutionalization of an interdiscipline (Frickel, 2004).

Miller (2000) describes the many ways in which framing of scientific issues is accomplished: ''economic analysis, elections, expert advice, judicial decisions, legislation, and numerous other social and communal practices'' (p 212). The conduct and interpretation of scientific research may also accomplish frame alignment, in that it is one particularly persuasive means by which social movement participation can be encouraged. Examination of the peer-reviewed work of the four climate–VBD proponents discussed in this article shows remarkable consistency with Frickel's description of how a collective action frame can motivate challenges to disciplinary boundaries. That is, this body of literature uses data concerning climate and VBDs (often preexisting data reinterpreted in light of climate change concerns) to justify a breakdown of traditional disciplinary boundaries. This is demonstrated by the striking number of papers in the climate–VBD literature that begin by affirming the reality and importance of anthropogenic climate change, before proceeding to explore its implications for VBDs (e.g., Patz et al., 1996, 2004; Patz and Lindsay, 1999; Haines et al., 2000; Patz, 2000; Epstein, 2001a, b, 2002; Haines, 2001; Patz and Khaliq, 2002; Haines and Patz, 2004; McMichael and Woodruff, 2004; Watson et al., 2005; McMichael et al., 2006). Interestingly, this statement becomes more implicit than explicit in recent papers (e.g., Haines et al., 2006a, b; Patz and Olson, 2006a, b; Patz et al., 2007, 2008; Frumkin and McMichael, 2008), perhaps reflecting the now less-contested nature of scientific consensus on the link between greenhouse gas (GHG) emissions and climate change. Following this affirmation, papers often end with hortatory statements concerning the need to reduce greenhouse gas emissions. As early as 1993, Haines, Epstein, and McMichael argue that ''the creation of a monitoring network must not be used as a ''wait and see'' argument against action to reduce greenhouse gas emissions'' (Haines et al. 1993, p 1469). Epstein (1995) calls for a ''renewed focus on primary prevention—that is, on the forms of development and the fossil fuel-based economies that drive global change'' (p 170). Another illustrative example holds that ''proactive policies toward reducing greenhouse gases should be considered along with more conventional disease prevention strategies'' (Patz et al., 1998, p 152). Haines, McMichael, and Epstein comment that ''recognizing the wide-ranging potential consequences of climate change for our health and well-being can greatly strengthen the international rationale for reducing greenhouse gas emissions'' (Haines et al., 2000, p 733). Statements such as these establish the scientific consensus on climate science as a frame within which VBD dynamics are interpreted as a symptom of climate change.

That this frame serves to motivate support for interdisciplinarity is suggested by the frequency and consistency of calls for interdisciplinary research found in climate–VBD papers that take as their starting point the reality of climate change. For example, McMichael (1993) calls for ''interdisciplinary research, using modeling and forecasting to estimate impact'' (p 7). Epstein (1995) recommends ''interdisciplinary, comparative, and collaborative epidemiology'' (p 170), while Haines and McMichael (1997) call for a ''multidisciplinary approach'' (p 870). In Patz (2000),

"analyzing the role of climate in determining human health outcomes will require interdisciplinary cooperation among health scientists, climatologists, biologists, ecologists, and social scientists" (p 57). Haines et al. (2000) call for "multidisciplinary research into the identification, understanding and modeling of health impacts" (p 733). Patz and Olson (2006a) urge "unprecedented co-operation between natural and social/health scientists" (p 547).

Finally, Patz and Reisen (2001) seem to be targeting a specific disciplinary boundary by calling in *TRENDS in Immunology* for "research by immunologists on the potentially large and widespread health risks from global climate change" (p 172). These examples are only the clearest expressions of the tendency to portray interdisciplinary research as a solution to climate change-related VBD impacts.

Reactive Boundary Work

Further evidence that climate change is serving as a frame to motivate challenges to disciplinary boundaries is found in the opposition to this movement. The peer-reviewed work of four scientists critical of climate–VBD research's quality and importance is extremely consistent with the definition of boundary work as an attempt to fend off challenges to disciplinary integrity from outsiders. In perhaps the earliest published evidence of this tendency, Rogers and Packer (1993) describe their own heuristic climate-linked model of tsetse fly distribution as "slightly to the right of statistics" on the scale of "lies, damn lies and statistics" (p 1284). Another relevant passage holds that it is "tempting to conclude that vector-borne diseases will become more prevalent as temperatures increase," but that this assumption is "at best naïve" (p 1283). Finally, the authors warn against "oversimplistic extrapolation of the present to some (incompletely specified but changed) future, and possibly warmer world" (p 1284). The paper draws a distinction between the responsible, methodologically rigorous perspective of traditional VBD science and the "tempting," "naïve" prospect of "oversimplistic" links between climate change and disease incidence. The authors further position their approach as the sober, responsible one by stating that "such predictions should not be used to frighten public health planners into precipitate action over the possible impact of global warming" (p 1284). This early paper shows Rogers and Packer defending their discipline from allegedly amateurish intruders, and is echoed repeatedly in the following years.

Such critical studies employ a number of methodological tools to show deficiencies in climate–VBD science (e.g., Rogers and Randolph, 1993, 2000; Reiter, 1996, 1998a, b, 2000a, b, 2001; Randolph and Rogers, 2000; Hay et al., 2002a, b, 2005; Shanks et al., 2002). These tools include criticizing the methods of climate–VBD research, demonstrating important non-climatic determinants of VBD incidence and prevalence, and publishing results in which climatically linked changes in VBD dynamics could reasonably have been expected, but were not detected using sophisticated scientific methods. A *Science* news story summarizes the content of this skepticism: that predictions of climate-related infectious disease increases are "soft science" carried out by outsiders to the field of infectious disease epidemiology; that such predictions are likely motivated more by hysteria over climate change than by sober scientific thought; and that attention paid to climate change's possible impacts represents an irresponsible distraction from the real factors behind the global distribution of VBDs (Taubes, 1997). As in our discussion of the proponents of climate–VBD science, we do not evaluate the scientific validity of these arguments, but instead focus on the rhetorical strategies employed in making them.

The nature of these strategies is suggested by Paul Reiter's contemptuous conclusion to an historical paper on climate change and malaria, in which he claims that "public concern should focus on ways to deal with the realities of malaria transmission, rather than on the weather" (2000a, p 10). Even more derisive is Reiter's contribution to an exchange in the correspondence pages of *The Lancet* (any emphasis that appears in the following quotes [other than Latin names of organisms] has been added to illustrate the rhetorical strategies being employed):

> [A]s a *medical entomologist*, I am disturbed by the tangle of *syllogistic delusions* in the health aspects of the debate, and the *Machiavellian* way in which they are presented to the public…Malaria transmission was never attributed to climate change, by *malariologists*…I worry about climate change, but my concern is with the dissemination of fallacious logic to journalists who are *more likely to focus on crisis than on reason*. (Reiter, 1998b, p 1738)

This passage highlights the disciplinary identities involved, implicitly contrasting the responsible, rational disciplines of medical entomology and malariology with the perspectives of Haines and Epstein, to whom Reiter is replying (Epstein, 1998; Haines, 1998). More subtle

examples consistently portray climate–VBD researchers as amateurs by contrasting them with the "experts" who oppose their work. In Reiter (2001), those suggesting a role for climate in African highland malaria resurgence are described as "*authors*" (p 151) (while Reiter does use the word "author" to refer to authoritative sources earlier in this paper [p 144], these include Horace, Lucretius, Martial, and Tacitus, and other "Latin authors" with little immediate relevance to present-day disciplinary boundaries); those who dismiss such claims are described as "*malaria specialists*" (p 152). In Shanks et al. (2002) (Simon Hay is a co-author of this paper, and Rogers, Randolph, and Reiter appear in the references), "several *researchers*" are said to have concluded that climate change is responsible for malaria resurgence in East African highlands; these results are disputed by "*experts in vector-borne disease biology*" (p 1406). In Hay and colleagues' (2002b) provocatively titled "Hot topic or hot air? Climate change and malaria resurgence in East African highlands," the tendency to portray climate–VBD researchers as amateurs and pseudo-scientists is especially clear. The authors describe how "*many* have concluded that the reported malaria increases and the reemergence of other vector-borne diseases are likely to be the result of…climatic changes"; in contrast, however, "there has been considerable dissent by *specialists in malaria epidemiology*" (p 530). These examples subtly contrast the amateurish proponents of climate–VBD science with the specialists opposing them; this supports our hypothesis that the preexisting disciplinary boundaries of VBD science have been challenged.

In addition to subtle and not-so-subtle portrayals of climate–VBD scientists as amateurs, the work of Rogers, Randolph, Reiter, and Hay consistently portrays their work as amateurish. In 1996, Paul Reiter comments that "*speculations* on the effects of global warming in the USA frequently include discussion of mosquito-borne diseases" (Reiter, 1996, p 622). Such "speculations" are later described as "*uninformed*"; furthermore, Reiter comments that "the *distortion of science* to make predictions of unlikely public health disasters diverts attention from the true reasons for the recrudescence of vectorborne diseases" (Reiter, 1998a, pp 839–840). In Hay et al. (2000), "studies that have emphasized climatic determinants of vector-borne disease epidemics" are in "sharp contrast to…epidemiological theory" (p 9335). In a later review paper, Reiter (2001) again describes the theories of climate–VBD researchers as "*speculations,*" and the use of climate-based models to predict future mosquito-borne disease prevalence as "*inappropriate*" (p 141), "*facile*" (p 158), and based on "*simplistic*" reasoning (p 153).

Hay et al. (2002a) describe "*speculation* on whether anthropogenic climate change is exacerbating the malaria problem," saying that such "claimed associations…are overly *simplistic*" (p 905). Later in the same article, the authors make reference to the high public profile of climate change as an explanation for these theories, consistent with boundary work's tendency to attribute ulterior motives to the alleged pseudo-scientists in question (p 908). In another article, the authors (including Simon Hay) refer to "widespread, recent *speculation* regarding malaria resurgences in response to climate change," highlighting "the attraction of the global warming hypothesis as an explanation of highland malaria" (Shanks et al., 2002, p 1407) This language implicitly characterizes climate–VBD claims as poor, politically motivated science, in keeping with the suggestion that those scientists making these claims are amateurs. Finally, all four of Rogers, Randolph, Hay, and Reiter collaborated in 2004 on a commentary entitled "Global warming and malaria: a call for accuracy" (Reiter et al., 2004). This paper responds to another in which climate and malaria are modeled in Africa (Tanser et al., 2003), and to commentary accompanying the article in *The Lancet* (Hales and Woodward, 2003). It describes "*speculations*" that malaria's range will increase due to climate change, and characterizes Tanser and colleagues' model and Hales and Woodward's commentary as "*typically misleading examples*" (Reiter et al., 2004, p 323). After supporting their dismissal of the research in question with various examples, the authors end by urging "those involved to pay closer attention to the complexities of this challenging subject" (p 324). The didactic, "helpful" tone of this statement is identifiable as boundary work in that it portrays the authors as impartial, responsible experts, and those they are criticizing as unscientific and in need of education. Thus, the language used by Reiter, Rogers, Randolph, and Hay repeatedly downplays the scientific credibility of those proposing climate–VBD links. In this, and in their repeated statements concerning the real causes of VBD resurgence, these authors employ boundary work techniques to reinforce disciplinary boundaries (whether of medical entomology, invertebrate zoology, or simply biology) against the boundary challenging actions of climate–VBD researchers. We have previously shown these boundary challenges to be consistent with the theory that climate change is serving as a collective action frame to motivate interdisciplinary research, a claim to which the opposition described above lends support.

Discussion

This study aimed to explain the controversy over climatic influences on VBDs through interpretation of themes in peer-reviewed papers on the subject in light of theories of interdiscipline formation through collective action framing and boundary work. The textual examples given above amply support the hypothesis that the theory of anthropogenic climate change appears to be serving as a collective action frame, within which VBDs are interpreted as climate change impacts, and interdisciplinary research is highlighted as the logical solution. The reaction to this movement by a handful of biologists also appears to display the characteristics of boundary work designed to shore up the legitimacy and credibility of those disciplines—medical entomology and related fields—threatened by the intended interdiscipline formation. One explanation for this resistance is that calls for interdisciplinary climate–VBD research frequently suggest outreach by the medical profession and other health disciplines, perhaps alienating medical entomologists and other biologists. Epstein (1995), for example, writes that "health professions and teaching institutions must reach across scientific disciplines to study the implications of accelerated environmental change…as interpreters to the public of the impacts of global change, the medical and public health professions can assume an influential role in policies that address our common safety" (p 170). Patz et al. (1996) say that climate-linked emerging infectious diseases necessitate "cooperation between physicians on the one hand, and climatologists, biologists and social scientists on the other" (p 221). And Frumkin and McMichael (2008) write that "the health sector needs to demonstrate leadership through its own activities, and by engaging collaboratively with a wide spectrum of other sectors" (p 407). It therefore seems that the envisioned interdisciplinarity is one in which physicians and health scientists play a leadership role. This is very much in keeping with Frickel's (2004) observation that the framing of genetic ecotoxicology also kept its proponents firmly in control of agendas and priorities for the emerging interdiscipline.

Another potential explanation for the interdisciplinary conflict is provided by the role of GCMs in science related to health and the environment. Frames often have characteristics of narratives or stories, models or hypotheses, or collections of unspoken assumptions or institutionalized beliefs and practices, depending on their degree of maturity or establishment (Miller, 2000). In the case of climate–VBD science and other climate change impacts research, the frame-as-model comparison is especially relevant, as knowledge of climate change as a phenomenon is inextricably linked to the science of climate modeling, and to the global-scale framings that this encourages. An "epistemic" community consisting of scientists, policymakers and non-governmental organizations is said to have coalesced around the belief that GCMs are the best tool to represent nature and make decisions about the climate (Gough and Shackley, 2001). Climate modelers have lobbied for political support and funding for GCMs at the expense of other allegedly valid tools for studying climate (Shackley et al., 1998). Taylor and Buttel (1992) refer to a hierarchy of physical over life and social sciences in climate research, and Boehmer-Christiansen (1994, p 146) describes the "somewhat imperialist act" by which the World Meteorological Organization (one of the United Nations bodies most involved in the IPCC) extended its scope to include research on climate change impacts in the 1980s. The hegemony of GCMs within climate science has led to the increasingly global-scale framing of climate change impacts, with implications for the "different modes of scientific research and political organization necessary to respond to them" (Miller, 2000, p 217). Impacts research requires that researchers outside the climate modeling community (e.g., ecologists, geographers, social scientists, and infectious disease specialists) study the implications of various changes in the earth's climate, based on GCM outputs. These researchers must rely on the outputs of the handful of GCMs running worldwide, and are therefore put in a lay position with respect to climate modelers (Demeritt, 2001a, b). Those scientists concerned with the potential effects of climate change must organize their research around GCMs, and a scientific hierarchy is said to have emerged with climate modelers at the top (Taylor and Buttel, 1992; Cohen et al., 1998; Shackley et al., 1998; Demeritt, 2001a).

It appears reasonable that this hierarchical situation could lead to conflict, and challenges to the use of GCMs in VBD research do exist. Rogers and Randolph allude to "the degree of accuracy required of GCMs if they are to be of any use to biologists" (Rogers and Randolph, 1993, p 269). Later, the same authors comment that "the usefulness of GCMs as a basis for making predictions about the future of biological systems needs further clarification" (Rogers and Randolph, 2000, p 1765). This portrayal of GCMs—as possibly relevant resources to be drawn on by biological scientists—contrasts with the typical attitude found in much climate–VBD work, namely that GCM outputs can

and should serve as a starting point for research. Thus, Randolph and Rogers comment that ''predictions [of tick-prevalence] can only be as good as the climate scenarios upon which they are based'' (Randolph and Rogers, 2000, p 1743). In Randolph (2001), climate data is described as ''much cruder'' than satellite-derived data (p 1050), a point that is repeated 5 years on (Rogers and Randolph, 2006, p 365). In this last paper, a comprehensive review of climate change and VBD research, Rogers and Randolph explain that ''If climate change is to have any effect at all on vectorborne diseases, it must do so through the intermediaries of the parameters and variables of the R_0 equation'' (p 348). By compelling readers to ''pass through'' an equation from infectious disease epidemiology, this statement places biology and (implicitly) good biologists in between climate change science (and scientists) and assessment of socially and biologically meaningful outcomes.

Beyond issues of primacy in science related to VBDs, however, the global-scale framing of climate change impacts is relevant to the appropriate scale of intervention for public health programs. An implicit—and sometimes explicit—conclusion that can be drawn from links between climate change and VBDs is that actions to mitigate climate change would benefit public health (e.g., Epstein et al., 1998; Haines et al., 2000; Hales and Woodward, 2003; Kovats and Haines, 2005). This seems to contradict a recommendation with which Paul Reiter—who has spent a considerable portion of his career working for the US Centers for Disease Control and Prevention in mosquito-borne disease control—ends a skeptical review of climate and insect-borne disease:

> The natural history of mosquito-borne diseases is complex, and the interplay of climate, ecology, vector biology, and many other factors defies simplistic analysis. The recent resurgence of many of these diseases is a major cause for concern, but it is facile to attribute this resurgence to climate change. The principal determinants are politics, economics, and human activities. A creative and organized application of resources is urgently required to control these diseases regardless of future climate change. (2001, p 158)

That appropriate interventions are likely to occur at scales smaller than that of the global climate is clear from Reiter's conclusion. While it would be overly simplistic to divide infectious disease researchers into rigidly defined camps, it is possible to discern general themes with scalar implications. King (2004) describes how the early 1990s saw many biomedical scientists in the United States arguing in public forums that diseases such as HIV, Ebola, and other emerging or resurging diseases had global-scale causes—urbanization, migration, global commerce, global environmental change—but local-scale solutions (i.e., at the scale of their laboratories or research programs). Viewed in this light, the ''at best technical, and at worst merely self-serving'' (Waltner-Toews, 2001, pp 16–17) interventions recommended in the landmark 1992 US Institute of Medicine (IOM) report on Emerging Infectious Diseases (Lederberg et al., 1992), represented a reframing of infectious diseases that furthered the professional interests of the scientists who carried it out. This is consistent with the idea of an emerging diseases ''worldview,'' an overarching narrative (or frame) that structured thinking on causality related to globalization and infectious diseases in a comprehensive and persuasive fashion (King, 2002). In particular, it tended to propose solutions such as disease surveillance using sophisticated laboratory equipment, vaccination programs, vector control, outreach programs, and basic scientific (usually pharmaceutical) research. This type of rescaling process, famously described by Latour with respect to Louis Pasteur's microbiological solutions to 19th-century France's national preoccupations, privileges laboratory research as a remedy to larger problems. The unsurprising result of this rescaling is typically an increase in power and financial resources for those carrying out the rescaling (Latour et al., 1983; Latour, 1993). In this light, it is possible to draw a distinction between global scale action on climate change (or climate change adaption), and Reiter's ''creative and organized application of resources,'' which would appear to correspond more closely with the recommendations of the IOM report. This helps to demonstrate the nature of the stakes in the climate–VBD controversy by clarifying how research and intervention resources are allocated, and highlighting some of the recent battles that have been fought over them. That the scale-linked narratives of emerging infectious disease research would conflict with the framing provided by anthropogenic climate change is perhaps unsurprising; nevertheless, it is important to recognize in interpreting climate change impacts science, and reactions to it.

Alternate Framings

King's (2004) description of the scale politics of emerging disease research contrasts the laboratory-scale interventions

advocated in the IOM report, not with global-scale action on climate change mitigation, but rather with the focus on primary health care put forth in the Alma Ata Declaration and the Ottawa Charter on health promotion. This contrast suggests other interpretations of VBDs and climate than those put forth by either of the two camps of scientists described in this paper. Miller (2000) observes that critical analysis of framings can allow the identification of systematically excluded voices. Following our discussion of the framing of climate–VBD science, we here point out ideas and concepts missing from the discussion. In particular, we focus on how critical considerations of equity are absent from both sides of the debate, with the likely unintentional result being implicit normalization of the present-day global economic order (Brisbois, 2008).

Paul Reiter (e.g., 2008) has frequently countered claims that climate change is affecting VBDs by referring to specific manifestations of "globalization," such as urbanization and transport (one example is the transoceanic trade in used tires as a means by which dengue's mosquito vector spreads). At no point does this discussion of what Reiter calls globalization address its market-based causes and fundamentally "disequalizing" character (Cornia, 2001; Harvey, 2007), although these appear relevant to the distribution and control of VBDs. For example, many of the countries of Sub-Saharan Africa—which Reiter rightly identifies as having suffered "degradation of the health infrastructure" (2008, p 387)—have done so since the 1980 s in large part because of structural adjustment programs (SAPs). SAPs were packages of economic reforms imposed by international financial institutions on debtor countries as a condition of badly needed loans, with largely damaging consequences for health system functioning, nutrition, and many of the other social determinants of health with relevance to surviving and controlling VBDs (Babb, 2005; Equinet, 2007). The relevance of inequity and poverty to malaria and other VBDs (Chaves and Koenraadt, 2010) is not absent from Reiter's work, but his focus on the superficial manifestations of globalization without discussion of the powerful forces controlling it implicitly accepts its underlying "neoliberal" economic orthodoxy. And while SAPs are certainly not the only aspect of political economy relevant to health systems—and environmental change—in Sub-Saharan Africa, they provide an illustrative example of how Reiter's analysis could profitably be deepened.

On the other side of the debate, Patz et al. (2007) characterize climate change's health impacts as an "ethical crisis" in that they will be felt disproportionately in those countries least responsible for creating the problem through GHGs. This portrayal of the Industrial Revolution as the driver for climate change serves to highlight a glaring lack of attention to associated processes such as colonialism and subsequent related processes of neo-liberalism. That is, vulnerability to VBDs and other well-studied climate change impacts is a function of historical *and ongoing* trends towards exploitation of the global South by wealthier countries—those countries, it should be pointed out, where climate change projections and scientific knowledge of VBDs (along with GHG emissions) are largely generated. By starting with GHG emissions and using GCM outputs as the basis for ethical discussions, impacts research runs the risk of normalizing the ethically problematic economic world order in an effort to forestall future climate change-related problems. That is, if "ethical crisis" is how we describe climate change impacts, what language is left for the present-day economic order, with its roots in colonialism and neo-liberalism? This is consistent with the view that climate change has been constructed as an environmental problem, through a reductionist approach to modeling in which physical climate parameters are separated from their human implications (Cohen et al., 1998; Demeritt, 2001a, b). Another implication of our analysis is therefore the need to remember that "globalization," climate change, and health outcomes are linked to systematically inequitable global power structures that would handicap any number of interventions aimed at VBDs—global, national, *or* laboratory scale—in their effects on population health in the global South (see People's Health Movement et al., 2008; Labonte and Schrecker, 2006; and Farmer, 2005, for discussions of the political economic barriers to improved population health in the global South).

Latour (2005) cautions against using social theory to explain the actions and motivations of social actors without paying attention to what they are actually saying and doing. We acknowledge that our analysis to this point is vulnerable to such criticisms, and we can be accused of claiming to know what the actors in this controversy are intending and meaning better than they do. We have attempted to limit ourselves to pointing out congruence between the work of eight scientists and relevant social theories, drawing on close reading of peer-reviewed texts as primary sources. It is virtually certain that there is more to the controversy than what we have been able to explain. For example, attention to global health equity is

not absent from the work of any of the four proponents of climate–VBD science discussed in this paper (e.g., Ramin and McMichael, 2009). Suggestions that McMichael, Haines, Patz, and Epstein are insensitive to considerations of international political economy would be, in the words of an anonymous reviewer of an earlier version of this article, ''infelicitous in the extreme.'' When queried by the first author on the possibility that climate change-related framings of health impacts in the global South may implicitly normalize the inequitable global economic order, for example, Jonathan Patz's response was that climate change mitigation and adaptation provides a potentially useful vehicle for addressing a number of social issues, in addition to the global climate [J. Patz, personal communication, December 2008]. This perspective raises questions over what risks are involved in the political choice of using climate change, with its origins in computer models, academia, and governments in the global North, to organize and motivate challenges to global health inequity. One of our primary goals in writing this article was to spur further discussion on this point.

To summarize, therefore, the evidence discussed here strongly suggests that the theory of anthropogenic climate change is serving as a collective action frame for some researchers. These researchers discuss VBDs in such a way that the reader is encouraged to conclude that more interdisciplinary research—led by physicians and other health scientists—on the subject is necessary. Resistance to this framing appears to be based on preserving preexisting disciplinary boundaries in VBD research, and also to react to the scale-linked and hegemonic role of GCMs in science related to the climate. It is our hope that this article triggers a discussion on more self-reflexive and politically aware environment and health research and policy, with unwavering recognition of global health inequity, its roots in international political economy, and the role that researchers play—or could play—in confronting these challenges.

Acknowledgments

The authors acknowledge Abdel Maarouf, Kaila-Lea Clarke, Brie McAloney, and Margot Parkes for providing scientific and editorial advice at various stages in the research and writing of this article.

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