Visualizations of mosquito risk: A political ecology approach to understanding the territorialization of hazard control

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1. Introduction

Visualizations, such as maps and model outputs, have been used for centuries to condense and convey geographical information, with recent developments focusing on the interactive capabilities of computer-based geovisualization. Lately, epistemological boundaries have been blurred through the incorporation of geographic visualizations as analytic tools in social science research. Using visualizations as representations of quantitative data and qualitatively evaluating their impact on their creators and observers has spurred numerous studies within geography (Knigge & Cope, 2006; Nightingale, 2003; Robbins, 2003; Rutchick, Smyth, & Konrath, 2009).

With the expansion in technical capacity, however, came increasing scrutiny of the political implications and effects of geographic visualization. Early use of new visualization technologies such as geographic information (GIS) were exposed to common critiques of maps focused on the uneven power relations embedded within the production of scientific knowledges at the expense of “non-expert” ways of knowing and visualizing space that reproduced hegemonic power structures through mapping (Harley, 1989; Miller, 1995; Pickles, 1995; Wood, 1992). Conversely, feminist geographers, among others, have noted the utility of GIS as a method to break open new realms of interpretation instead of masking them, allowing more nuanced exploration of research questions (Kwan, 2002; Pavlovskaya, 2006). The net effect of these observations is the recognition of both the power-laden character of mapping and its concomitant political analytical possibilities.

Scholars within the field of political ecology have recognized the power of these visualizations, but have less frequently used visualizations as a tool for political ecological analyses themselves. The subfield explores the spatial and temporal connections among material

nature, social systems, and political economy. This approach empirically investigates the social construction of environmental problems and examines the power structures behind these constructions (Blaikie, 1999; Robbins, 2012; Watts & Peet, 2004; Watts, 2000).

In this paper we explore the use of hazard maps and their potential to delve into new areas of research that would otherwise not be possible by combining a dynamic mosquito life cycle model with remotely sensed imagery. This coupling produced two map-based visualizations of mosquito abundance risk in Tucson, Arizona that were shared with participants via focus groups. The results illustrate new interpretations of hazards and risk in terms of their politics of responsibility, illuminating connections, schisms, and associations among residents and county health officials, and revealing understandings, beliefs, and actions that were previously undiscovered. A political ecology approach combined with visualization methods highlights the discourses that permeate public health concerns and interrogates the production of these discourses. At the same time, this research forces the recognition that the production of hazard maps themselves exerts political influence and reproduces the often uneven power dynamics between map creators/presenters and research participants (in this case, Tucson residents and county health officials). It further illuminates the inevitable role of such mapping exercises in creating or re-instantiating territorial notions of fear or threat.

Focusing on perceptions of mosquito spaces in Tucson amongst the public and health agency officials, this research explores the use of visualizations as an analytic method in political ecology. The following section provides a review of current approaches using visualizations in political ecology and concludes with our research questions addressing gaps in this literature. Following that, we present our case study of mosquito management in Tucson, Arizona and our methodological approach incorporating surveys, visualizations, and focus groups. After this, the

results are presented, addressing how visualizations can aid in discerning notions of territoriality and responsibility in ways other methods cannot achieve. Our discussion addresses the power of visualizations, and we conclude with the importance of this line of work for hazards research in political ecology.

2. Visualization and Political Ecology

Research utilizing visualizations as a tool to link both qualitative and quantitative approaches in geography has spanned across sub-fields ranging from political geography to cultural ecology and feminist geography to GIScience. For example, Rutchick, Smyth, and Konrath (2009) demonstrate how quantitative electoral data translated into red and blue binary maps of the U.S. states increases voter perception of a polarized nation and propagates the opinion among residents that their votes do not matter in determining election results. In a different vein, Knigge and Cope (2006) developed the methodological approach of grounded visualization, whereby the social theory grounded in every day practices and visualizations are combined to uncover the human experience of place in ways that could not be seen otherwise. They use a combination of participant observation with neighborhood maps to explore how racial groups form attachments to place and shape these spaces, arguing that this approach is iterative, exploratory, and allows the existence of multiple interpretations.

Visualizations have also been an important tool within physical geography, particularly within the broader hazards tradition (for a brief overview, see Montz & Tobin, 2011). Time lapses of aerial images have been important for delineating hazardous sites (Campbell, 2007). Remote sensing technologies allowed for the development of more sophisticated algorithms inclusive of satellite data to study hazards such as drought (Kogan, 1995). Further advancements

in GIScience facilitated the application of these technologies to numerous natural and physical hazards and emergency situations (Cova, 1999). Despite these advancements, “analyses directed to testing the effectiveness of visualization in communicating risks are not common” in hazards and applied geography work (Montz & Tobin, 2011, p. 3), demonstrating an ongoing need to investigate the social work of, and response to, visualizations. Within hazards research a shift towards the social nature of hazards, focused on the social response to risk and the production of marginalization, marked a disjunction from a typically earth-science dominated framework (Burton, Kates, & White, 1968; O’Keefe, Westgate, & Wisner, 1976). Growing out of this tradition, a political ecological approach to hazards considers not only the hazard in terms of its biophysical content, but also its political economic factors (Liverman, 1990). It is this focus on institutional and social components that separates political ecological hazards work from the hazards research more dominant in physical geography.

However, within the field of political ecology, the use of geospatial visualizations as an analytic tool for exploring environmental hazards remains underexplored, particularly pertaining to debates and contestations of risk. GIScience techniques have been promoted as an effective research methodology within the realm of human ecology (Turner & Taylor, 2003), but room remains for exploring the political and economic implications of visualizations. More common uses of visualizations include interrogating an issue of importance to the field of political ecology, rather than investigating the impact of the visualizations themselves. For example, Heynen’s use of remote sensing technology (2006) to illustrate the relationship between tree cover and racial group access to trees illustrates underlying issues of equity, though the use of these maps is not integrated into the solicitation of results.

This is not to say, however, that political ecologists have ignored developments in GIScience and visualization. Some political ecologists have engaged visualizations, such as maps, to counteract structures of power, a central component of political ecological praxis. Political ecologist Nancy Peluso (1995) used the term “counter-mapping” to refer to the use of technical mapping to counteract hegemonic power structures, enabling counter-mappers to make their own claims to resources. Also using maps to disrupt traditional power structures, Rocheleau and Edmunds (1997) call for more explicit “gender mapping” because traditional land tenure maps obscure women’s spaces in forest management and household provision. A political ecological lens on these techniques of counter-mapping and visualizations highlights the power struggles behind mapped discourses (Bryan, 2011; Hodgson & Schroeder, 2002; Sletto, 2002).

Maps and other visualizations can be used to further explore the impact of visualizations on political environmental subjects whose environmental behaviors are the target of management (Agrawal, 2005). For example, by asking land users and professional land managers to identify land cover categories depicted in photos of local forests and comparing these to ecological categorizations, Robbins (2003) used divergent maps to analyze, and not merely reflect, multiple representations. This paper attempts to bridge the gap among hazards, health geography, critical visualization, and political ecology by using visualizations of risk in this way, as an analytic tool.

When using visualizations as an investigative tool, certain kinds of politics emerge that are not evident through other methods. For example, Knigge and Cope (2006) use ethnographic data to find and map the existence of community gardens otherwise rendered invisible by traditional GIS analysis. The incorporation of visualizations in conjunction with ethnographic data unveils political divisions – the distribution of community gardens along racial and economic lines – not seen using only one method or the other. Similarly, Nightingale’s (2003)

use of ecological oral histories and aerial photo interpretation result in divergent conclusions between methods. The tendency of mixed methods to produce divergent results, she argues, is not a failing of triangulation, but instead an opportunity to realize how knowledge and opinions emerge from the unique position from which one observes the world. Thus, visualization, especially when coupled with ethnographic and survey methods in political ecology, may open the door to novel insights, particularly under conditions of diverse and plural knowledges and understandings of the environment. This use of visualizations also unveils the territorial implications that frequently emerge from environmental politics: competing views of responsibility for, or authority over, ecological systems and human health. Here, territory is understood as a space where individuals and/or groups “affect, influence, or control people, phenomena, and relationships by delimiting and asserting control” (Sack, 1986, p. 19), which includes “proscribing or prescribing specific activities within spatial boundaries” (Vandergeest & Peluso, 1995, p. 388). A political ecological approach to visualizations enables the exploration of power, environmental risk, and territorial conflicts among groups and individuals, such as the case of mosquito control.

2.1 Research Questions

Building upon this previous work in a variety of geographical fields, we contribute an underutilized analysis of visualizations. Within this context, we present multiple versions of mosquito risk in Tucson to both residents and county health and vector control officials. The use of these visualizations of alternative risk scenarios allows us to delve into notions of citizenship, civic responsibility, authority, and territory that emerge in surveys and focus groups with both residents and public health officials. Informed by Nightingale (2003), we view combining these quantitative (visualizations of models of mosquito risk) with qualitative (discussions with

managers and homeowners) methods as an opportunity to observe political nuances that do not emerge with previous survey methods. By disrupting the norm of presenting risk and hazard maps as authoritative, this study aims to delve into how the visualizations of environmental risks are themselves political (Robbins, 2003). Our work also interrogates how visualizations of risk impact environmental subjects (Agrawal, 2005) and their notions of responsibility.

Using the framework of political ecology (Robbins, 2012) to address the analytic tool of visualizations, our research addresses the following overarching questions:

1. *How can visualizations of public hazards be used to discern notions of responsibility and territoriality?*
2. *What contributions towards understanding the politics of hazards can visualizations provide that other methods cannot?*
3. *How does using these visualizations reflect and/or produce understandings of territory?*

3 Methods

3.1 Case study: Mosquitoes in Tucson, Arizona

Few problems invite the use of spatial techniques as much as local health geographies (November, 2008). Our research focused on neighborhood-scale exposure to an important disease vector in the U.S. Southwest: the common mosquito *Culex quinquefascitus*.

Despite Tucson's desert habitat, mosquito populations and the diseases they carry have been reported in the area for centuries. Malaria and swarms of mosquitoes were recorded by early European settlers in Southern Arizona (Dobyns, 1976; Fink, 1998; Teeple, 1929). Mosquito numbers dropped in the mid-20th century due to altered hydrology and the widespread use of DDT, but in the past 25 years mosquito populations have grown with increases in restored

wetlands and more complex urban landscapes (Fink, 1998; Karpiscak et al., 2004; Willott, 2004). Once thought of primarily as a nuisance due to the relatively rare incidence of mosquito-borne illness in the region, the emergence of West Nile virus (WNV) has reinserted the mosquito as a public health hazard in Arizona. After the first cases of WNV appeared in New York in 1999, the disease quickly traveled throughout the United States and emerged in Arizona in 2003. While WNV cases in many other states have receded, cases in Arizona have remained relatively constant and increased with a nation-wide outbreak in 2012 (Table 1). While WNV remains a relatively rare and often self-limiting disease, its consistency in Arizona has given health officials and the public cause for concern. Additionally, dengue fever has exhibited sporadic outbreaks in southern portions of the United States (Texas, Florida and Hawaii, as well as Sonora, Mexico), and could appear in Arizona, particularly under changing climatic conditions (Bouri et al., 2012). While mosquitoes may primarily be a nuisance to residents, they also pose a health hazard that has the potential to become more severe in the coming years.

With the increased threat posed by mosquito-borne diseases, state bodies for managing these public health hazards were forced to adapt quickly (xxx 2008, masked for blind review). County health control districts and vector control agencies utilize a variety of methods, based on different understandings of mosquito ecology, management techniques, public opinion, educational background, and technology (xxx 2008, masked for blind review). For example, only separated by 100 miles, the cities of Phoenix (city population of 1.4 million) and Tucson (city population of 525,000) employ radically different mosquito management strategies despite their similar climates ("2011 U.S. Census," 2011; xxx 2010, masked for blind review). Phoenix's Maricopa County Vector Control office employs GIS mapping, sophisticated trapping, and fogging for adult mosquitoes throughout the city (xxx 2010, masked for blind review).

However, Tucson's Pima County Health Department (PCHD) management strategy focuses on homeowner education to address breeding sources, and responds to complaints with localized larvicides. Health officials in Tucson believe in the efficacy of a public participation-based management strategy that attempts to encourage personal responsibility in homeowners to remove sources of standing water, which health officials argue is the most effective way to reduce mosquitoes at their origin (xxx 2010, masked for blind review). This project integrated three methodological approaches: resident surveys, risk maps, and focus groups. For more detailed discussion of the methods and analysis used in the various components of this project, see (xxx 2011, masked for review; xxx 2012; xxx 2010; xxx 2008; xxx 2012; xxx 2010; xxx n.d., in review).

3.2 Visualization of mosquito abundance risk

To address the utility of visualizations in eliciting perceptions concerning risk and responsibility, modelers in our research group created maps of potential mosquito abundance using a dynamic simulation model integrated with remotely sensed imagery. The primary goal in the creation of these maps was to produce a detailed visualization of fine-scale mosquito risk in Tucson that incorporated detailed microclimatic data. A land cover classification was created using 2010 National Agricultural Imagery Program multispectral imagery, derived Normalized Difference Vegetation Index (NDVI), and Light Detection and Ranging (LiDAR) canopy height model data for the city of Tucson (xxx 2011, masked for blind review; xxx 2012, masked for blind review). Land cover variables derived from the land cover classification were used to inform the Dynamic Mosquito Simulation Model (DyMSiM) (xxx 2010, masked for blind review). DyMSiM is a dynamic model that simulates the development of the mosquito

throughout its lifecycle based on parameterized ecological data and driven by daily precipitation and temperature input. Land-cover data was imported into DyMSiM along with daily precipitation and maximum and minimum temperature to generate daily populations of *Culex quinquefasciatus* (a mosquito that breeds in containers and is the primary vector of WNV in the region) across the city of Tucson during the monsoon season (June – September). All pixels were classified by the amount of impermeable surface (5 categories), amount of container cover (4 categories based on land-use classification), and temperature deviation from the Tucson Airport weather station based on the percentage of green vegetation coverage from NDVI (3 categories). DyMSiM was then run 60 times at a 10 m spatial resolution to represent each possible pixel classification and the model output for each run was assigned to the appropriate pixels. Higher coverage of impervious surfaces, higher container coverage, and cooler temperature (higher NDVI) indicated higher risk of mosquito presence. The use of daily temperature (significant due to its effect on development rates, mortality at all life stages, and the reproductive cycle of the mosquito) and precipitation data in conjunction with our mosquito life-cycle model across fine-grained aerial imagery offers a detailed view of mosquito populations in the city. Further specifics of model development, validation, and integration with remotely sensed imagery are described in detail elsewhere (xxx 2011, masked for blind review; xxx 2012, masked for blind review; xxx 2010, masked for blind review).

The final products of this model are high resolution maps showing areas most likely to host mosquito populations during the city's typical wet monsoon season. Risk classes of very low, low, moderate, high, and very high risk were determined by natural breaks among the number of mosquitoes predicted by the model to be present in each 10 m by 10 m model area during the monsoon season (the model at was run at 10 m resolution). The same risk class

categories (but not absolute values) were used for all resolution maps to make comparisons of risk across all maps easier. The scale for each risk class changed because the range in mosquito population was altered at different resolutions. An ordinal scale, rather than an interval scale, was displayed on the maps to avoid residents comparing actual numbers of mosquitoes to their own experiences, which we felt would distract from meaningful comparisons of mosquito abundance across the city.

All graphical representations of ecological data, however, require simplifications of ecological outputs, which can create further complexities (Zubrow, 2003). In this case, DyMSiM was run at 10 m spatial resolution, producing predicted mosquito populations at 10 m resolution and establishing the land cover-mosquito presence relationship for the study area. The 1 m resolution maps were created from proportionally calculating the number of mosquitoes for each 1 m by 1 m area from the 10 m by 10 m model output. Although the model was run at 10 m resolution, we chose to display 1 m resolution maps in order to visualize extremely specific details on local properties and parcels. This resolution was viewed as important to the investigation particularly because mosquito management in Tucson is focused on citizen and homeowner responsibility at the household scale. The 30 m resolution maps were produced by aggregating the 10 m by 10 m land cover DyMSiM inputs (based on the greatest proportion of land cover classifications) to 30 m by 30 m cells. Both maps used the land cover-mosquito presence relationship established at the 10 m spatial resolution, but changed the spatial resolution and aggregation of the land cover inputs.

Figures 1 and 2 depict the 1 m resolution maps that disaggregate risk, distributing it throughout most of the city neighborhoods with streets, street-side washes, and yards showing slightly higher risk. Conversely, managed public spaces such as parks and golf courses stand out

as clusters of low mosquito risk. The 30 m resolution maps (Figures 3 and 4) of the same data, however, identify the main risk areas as public spaces, such as parks, golf courses, washes, and streets, that are less evenly distributed throughout the city. In this aggregation, yards show lower risk. Aggregation of land cover data will generalize and smooth the surface, particularly in heterogeneous land cover areas, such as residential neighborhoods, where the lower spatial resolution is more likely to result in a different spatial distribution of mosquito populations than it does in more homogenous land cover areas, such as parks.

These differently aggregated maps illustrate the issue of generalization, whereby different ways of classifying and grouping statistical data and displaying them on a map requires explicit decisions by the map maker throughout the processes in choosing the most “realistic” representation of phenomena (Jenks, 1963). In this case, however, rather than imposing modeler/researcher discretion to select the more “accurate” interpretation, we chose to capitalize on this disjuncture (a form of the Modifiable Areal Unit Problem, or MAUP) in focus groups by including *both* depictions of the data (Dungan et al., 2002; Openshaw, 1984). The MAUP refers to “a challenge that occurs during the spatial analysis of aggregated data in which the results differ when the same analysis is applied to the same data, but different aggregation schemes are used” (Sommer & Wade, 2006, p. 132). MAUP often poses problems for modelers determining the most accurate display of their data, such as how aggregation of the “aerial unit” will affect the results. While MAUP effects are most often encountered through the aggregation of adjacent map units (as in the case of census data), in our case, aggregation of the land cover to a lower spatial resolution modified the “aerial unit.” As is clear from Figures 1 and 2, this resulted in a significant difference in the apparent spatial distribution of mosquito populations. This difference provided a tool for eliciting responses to different spatial expressions of mosquito hazards based

on a single model. We use this approach with the understanding that there are multiple ways of perceiving, representing, and interpreting mapped phenomenon (MacEachren, 1994), including different ontological orientations of vector control agencies (xxx 2010, masked for blind review).

[Figure 1 about here – 1 m resolution map of the city of Tucson]

[Figure 2 about here – 1 m resolution map of Cholla Vista]

[Figure 3 about here – 30 m resolution map of the city of Tucson]

[Figure 4 about here – 30 m resolution map of Cholla Vista]

3.3 Surveys and Focus Groups

Exploiting the visible differences in mosquito risk produced at the two spatial resolutions, we showed these maps to focus groups in May 2012, and asked participants to reflect on the congruence of the images with their own opinions and experiences. Three focus groups were conducted during evenings or on weekends in three neighborhoods in which 111 surveys of resident knowledge and management practices related to mosquitoes had previously been conducted in October and November 2011. These surveys were conducted to understand resident perceptions and attitudes pertaining to mosquitoes and their control in Tucson, the methods of which are detailed elsewhere (xxx n.d., in review).

We selected neighborhoods that were dispersed across central Tucson in order to overlap with mosquito-trapping sites that our research team managed. These mosquito traps were used to field-test the dynamic mosquito simulation model used to create the visualizations for the focus groups (see below). Using 2000 census data, the most recently available at the time, we chose three neighborhoods to represent low, middle, and high household incomes based on natural breaks in order to determine if wealth played a role in neighborhood mosquito management. These neighborhoods have been renamed Saguaro Hills, Cholla Vista, and Gates

Park within this paper to conceal the identity of research participants. Seven residents participated in the Saguaro Hills focus group, two in Cholla Vista and five in Gates Park. Participants were recruited primarily from the pool of survey respondents who expressed interest in being re-contacted for follow-ups. Recruitment through neighborhood email listservs garnered three additional participants that had not previously taken the survey. An additional discussion was convened with local health officials representing both office and field staff of the Pima County Health Department (PCHD).

We began the focus groups with an overview of the project and explained our interest in resident perceptions and practices related to mosquito control. We then informed participants that the specific purpose of the focus groups was to gauge how accurately different representations of the modeled and mapped mosquito risk maps reflected their own spatial perceptions of mosquito risk. We first displayed simple aerial images of Tucson and the participants' neighborhood that showed no modeled risk of mosquitoes (similar to Figures 1-4 but without the model overlay). After orienting participants to the image by highlighting key features such as streets, washes, and landmarks, we asked the group where they expected high and low abundance of mosquitoes and why. This allowed for assessment of the types of ecological landscapes participants associated with mosquitoes without the influence of modeled risk.

Before displaying our differently aggregated maps, we explained that the maps were created by modelers in our research group and reflected four main inputs (described above): impermeable surfaces, amount of container cover, temperature, and precipitation, coupled with remotely sensed vegetation coverage. We emphasized that the maps were two representations of the same data and that neither was inherently more "accurate" than the other but rather served as

a tool for residents to explain which map more strongly reflected their opinions. We then displayed the 1 m resolution maps of both the city of Tucson and residents' specific neighborhood (Figures 1 and 2) and asked residents to express whether they agreed or disagreed with the visualized representation of mosquito risk. This included discussions of whether they felt the map over or under-represented mosquito risk in certain locations, and why. We then asked participants to explain the types of control measures they would like to see based on the portrayed mapped risk, addressing how these visualizations could be used to discern beliefs of territory and responsibility for hazard control (Questions 1 and 3). Following this discussion, we presented the 30 m resolution maps of the city of Tucson and residents' specific neighborhood (Figures 3 and 4) and asked the same questions. After both maps had been presented, we asked participants which map they felt better reflected their understanding and day-to-day experience of mosquito ecology and distribution in Tucson. We used this approach to understand how participants reconciled their own ecological understandings of mosquito spaces with mapped risk by interrogating *why* residents believed mosquitoes were more prevalent in certain areas. Asking residents to make these comparisons between map resolutions also allowed us to explore how residents' ideas of responsibility and management changed with different representations of the data. Additionally, health officials from PCHD were shown maps depicting the city of Tucson and each neighborhood where focus groups had been held and asked the same questions. The three neighborhood focus groups were recorded and transcribed for the purposes of analysis. These results were compared with previous survey results in order to understand the contributions of visualizations to political ecological understandings of hazards (Question 2).

4. Results

By using the tools of visualization in focus group settings and comparing responses to previous work (n.d., in review, masked for blind review), the results directly address how visualizations of hazards can be used to discern notions of responsibility and territory and provide contributions towards understanding the politics of hazard control.

4.1 Visualizations of public hazards as a tool to discern notions of responsibility and territory

The two maps shown to focus group participants displayed different spatialities of mosquito risk, due to the MAUP effect described above. One meter resolution maps (Figures 1 and 2) tended to depict mosquito distributions as: 1) highly disaggregated, 2) scattered within and around residential areas, including and especially resident yards, and 3) spread relatively more evenly throughout neighborhoods and the city. In contrast, 30 m resolution maps (Figures 3 and 4) tended to show mosquito distributions as: 1) heavily concentrated rather than dispersed, 2) centered in public spaces, including rivers, arroyos, large parks and golf courses, and 3) unevenly distributed around neighborhoods and the city more generally.

When faced with these differing images, all three neighborhood focus groups came to the same conclusion: the 30 m resolution maps were a more accurate depiction of mosquito hazards in the city. When homeowners were presented first with the 1 m resolution maps, several were skeptical of their veracity. A homeowner in Gates Park, which is located adjacent to a golf course and large city park, commented, “We don’t have very much [risk] at all, I’m surprised.” Another participant from Saguaro Hills said, “It’s sort of surprising, though, I really would have thought that the managed green spaces would have come up at least yellow [moderate risk] on those maps.” Though some residents did note that houses and yards can be breeding sites, the consensus was that 1 m resolution images did not emphasize areas with the most risk.

When presented with the 30 m resolution image, conversely, residents expressed greater satisfaction with the maps' veracity. A homeowner in Gates Park remarked, "that's what we expected: the golf course and the arroyo and the park" are problem areas. A respondent from Saguaro Hills commented, that mosquito risk "follows the arroyos and rivers ... so it seems more realistic." Thus, despite their knowledge and management of mosquito spaces in their backyards, homeowners identified more strongly with mosquito risk maps placing breeding sites in public spaces. Again, this response was not universal. As one participant in Saguaro Hills remarked when looking at the 30 m resolution map, "So I don't know how accurate this is because a lot of people have issues at home. And this shows that most homes are low." Nevertheless, discussions in focus groups developed consensus around the higher congruence of their experience with the 30 m resolution images, and these maps stress mosquito habitat in public areas, rather than private, with a high level of concern directed towards irrigated spaces and waterways.

Beliefs of mosquito ecology were also interrogated to determine why residents picked certain locations as higher risk. When 30 m resolution maps showed a park as a problem area, a resident from Cholla Vista said, "That's the park. That makes sense ... It's got a nice bunch of shady trees, they water the grass; it's always green. Nice, kind of humid." One homeowner who takes frequent walks in Saguaro Hills commented, "They do water the park. They do water the grass. Because I know [when] I walk there, I get bitten." These characterizations of mosquito microecologies are partially correct: pooling water is likely to host mosquito larvae, provided it stands for several days (the length of egg gestation is dependent on the mosquito species). While mosquitoes cannot breed in moist grass without standing water, the humid environment of irrigated fields can attract adults. However, in addressing public and open spaces as the most

likely sources, homeowners were overlooking the myriad of microspaces in yards and homes that promote mosquito breeding. Additionally, the modeled mosquito species, *C. quinquefasciatus*, preferentially breeds in containers of water (which are most often found in residential areas than other land classifications) rather than open water bodies. However, this species is likely not the only that residents encounter, and it is nearly impossible to tease apart homeowner reactions to different mosquito species.

With these public spaces posited as hazard areas, residents expressed a desire for increased mosquito management by the authorities. When presented with 30 m resolution maps, a resident from Cholla Vista remarked that mosquito management, “really comes down more to the city, I mean the trouble spots on that [map] are all either businesses or they’re government-owned.” A respondent from Saguaro Hills commented when seeing the 30 m maps, “I think it put it more on the city and the county to manage public spaces.” Neighborhood residents felt these communal spaces that harbored mosquitoes were not under their control

In contrast to the resident focus groups, PCHD workers and officials described the 1 m resolution maps as more accurate. They suggested that the pinpoint identification of small drainages, especially culverts, precisely matched the areas where they spent the greatest amount of time performing management activities like placing BTI “dunks” (*Bacillus thuringiensis israelensis* is a group of bacteria toxic to mosquito larvae but few other species) and surfactants to reduce larvae populations. PCHD respondents were satisfied by the degree to which the more highly resolved images showed habitats in resident yards and private spaces. Yards, officials stressed, are the major source of mosquitoes that are likely to actually bite citizens and provide ideal habitat owing to standing water left by residents in containers, furniture, pools, and other residential amenities. These areas, moreover, are typically beyond the control of officials, and

were described as abiding problems for managers. County health workers repeatedly underscored that the 1 m resolution maps emphasized the effort citizens need to put into mosquito control. More than public green spaces and waterways, backyards full of water-holding containers were identified as crucial culprits for disease vectoring.

4.2 The unique contribution of visualizations to understanding the politics of mosquito control in Tucson

Surprisingly, the views expressed by residents during the focus groups were not evident in previous surveys conducted in these neighborhoods. The details of the neighborhood surveys are published elsewhere (xxx n.d., in review). However, we mention these results here in a comparative sense to demonstrate the work that maps can do. While focus group respondents most strongly agreed with maps that showed mosquito-risky spaces to be public areas such as golf courses, grassy parks, arroyos, and rivers, these answers were not prevalent in the surveys, where only 17% of survey respondents cited similar spaces as risky. In fact, the most common answers as to which spaces survey respondents noticed the most mosquitoes were “my yard” or “anywhere with standing water.”

Not only were perceived mosquito-risky spaces different in the focus group setting, but by extension, so too were recommended mosquito management strategies. Only 36% of survey respondents indicated a desire for increased authority management of mosquitoes in their neighborhoods (xxx n.d., in review). However, when focus group participants chose maps that highlighted parks and rivers as mosquito-prone areas as the most accurate representation of risk, residents expressed the need for active management in these spaces. At the same time, several focus group residents thought that these spaces might already be managed, as they are obviously

mosquito-prone areas. One respondent in Gates Vista said, “We walked around the perimeter of the park, and I run the perimeter, I haven’t noticed any mosquitoes. They must do a good job of controlling all the water that runs off the course.” Other focus group participants still emphasized the need for water source management and were afraid of aerial spraying, which was commonly cited as the dominant management option available to authorities. Despite these concerns, all three public groups concluded that these risky spaces must be actively managed by the city or county, a different sentiment than what was gathered through the individual surveys.

It should be noted that the residential focus groups (a total of 14 neighborhood resident participants) provided a much smaller sample size than the surveys (111 participants), but the consistency expressed among the three focus groups is significant. The 30 m resolution resonated strongly with these different groups (three non-adjacent neighborhoods reflecting low, medium, and high income levels), and all concluded that these public spaces called for control by city or county authorities that were responsible for these properties. That these different groups all displayed an affinity for the 30 m map, which stood in contrast to the health department’s valuing of the 1 m map, is a key result with implications for mosquito management in Tucson.

5. Discussion: Visualizations, Territory, and the Political Influence of Mapping

Based on the results from the focus groups, we argue two main points: (1) The change in resident perceptions of mosquito-risky spaces in the focus groups demonstrates the power of visualization, and (2) The fact that residents preferred the 30 m maps while health officials preferred the 1 m maps can be linked to notions of responsibility for mosquito control. This presents an important methodological avenue for political ecologists, but also requires us to consider a resulting politics of territory and resolution embedded within our own work.

The change in participant responses between the surveys and the focus groups is particularly interesting. It is possible that the focus groups attracted a small subset of individuals with the pre-existing opinion that public spaces pose a higher risk of mosquitoes. However, we suspect that is not the case for two important reasons. First, there was a small number of survey respondents (< 20%) that cited public spaces as being risky. It would be unlikely that only those from that small minority would agree to participate in the focus groups. Further, when inviting residents to participate in the focus groups, they were told that they would be shown two different map outputs of mosquito risk in their neighborhood/city, and would be asked to discuss how these maps matched their own experiences and understandings. The discussion of public/private space and individual/state control in relation to the maps was generated out of the focus groups. Therefore, we assert that the visualizations in the focus groups uncovered different responses than the neighborhood surveys of residents. This indicates the ability of visualization models to explore schisms and associations in ways that cannot be achieved through other methods.

When considering the array of methods at our disposal as geographers, it should be not be surprising that different methods can generate different responses. As Nightingale (2003) suggests, “the silences and gaps between data sets can be explored to interrogate the partiality of knowledge produced in different theoretical and methodological contexts.” These gaps, seen in the different response between surveys and focus groups, are not uncovering poor or incomplete methods but instead demonstrating how multiple methods reveal different ways of understanding mosquito spaces of risk.

The use of images influences participants due to their *visual* nature, which may account for some difference in responses from *oral* surveys. This is evident by linking participant

understandings of mosquito habitat to the maps. The consensus of risk being highest in public spaces stemmed from focus group participants' understanding of a mosquito ecology that ties the insect to non-native vegetation needing irrigation in the desert climate, and water courses (such as river beds and washes) that have the potential to hold standing water. When looking at a map, these features are more easily labeled and knowable in public spaces, as compared to an indeterminate number of conditions in private yards. This may help to explain why at an individual level, participants aware of their own mosquito-producing habitats in their yards are quick to internalize responsibility, but when the habitat becomes spatialized, it becomes easier to "know" in public areas. Indeed, Tucson residents in focus groups might have in part responded most strongly to the 30 m resolution maps because visualization of mosquito risk in aggregated public spaces creates maps that are more easily labeled "problem areas", with delineated boundaries for control and clearer steps towards action.

The second important point is the preference of the PCHD for the 1 m map. Such a conclusion from PCHD agents is congruent with the overall emphasis of the city's mosquito control policy, which relies heavily on a "Fight the Bite" campaign directed at changing citizen behaviors to increase awareness and household responsibility to abate mosquito breeding (xxx 2010, masked for blind review). This campaign was mentioned in one focus group, but was not explicitly recognized as a management strategy from Pima County by many residents. Maps aggregated at 1 m appear to match officials' belief that residents need to manage microhabitats in order to effectively combat mosquito problems. Though entirely converse to the response of citizens, the pattern is congruent: PCHD conceptions of mosquito *ecologies* are again linked to notions of mosquito *responsibilities*, placing mosquito control at least in part onto the shoulders of individuals. Political ecologists are poised to explore "in controlled and quantitative terms the

convergence and divergence of knowledge, categories, and ecological subjectivity” and thereby “can outline the fault lines along which potential conflicts arise” (Robbins, 2003). In our case, the maps became the analytical tool to outline ecological spaces of risk and responsibility in participants’ minds.

Ultimately, different management outcomes were recommended based on which map spoke most strongly to viewers’ spatialized perceptions of high and low areas of mosquito risk. As MacEachren (1994, p. 456) notes: “If a realistic landscape representation is used, the audience tends to treat the plan as final – not as subject to question. In contrast, if maps and/or drawings are used, the plan is treated as a proposal open for comment”. So too, we suggest, using two distinct visualizations of the same data leaves an opening for a discussion different than a single, “final” map would have. Therefore, by using these maps as a tool, we were able to elicit opinions of territoriality (who is responsible for public health on what territories) as well as contradictory perceptions of mosquito ecological habitats.

However useful these maps are for *eliciting* reflections of territory, they are also undeniably complicit in *reproducing* territorial notions of hazards and responsibility. This leaves open the possibility that these maps are producing mosquito fears and creating new mosquito-risky spaces in the minds of observers. Visualization techniques themselves are political interventions with potentially unforeseen implications, including the form visualization takes, as demonstrated by the MacEachren (1994, p. 456) quote above. The maps presented to participants in our study were but two of countless possible representations of Tucson’s mosquito landscape. Data aggregated at a different spatial scale, or represented in other ways, elicits different responses, and helps create, and not merely reflect, an ecological and territorial perception. Based on modeled inputs of remotely sensed imaging and knowledge of mosquito ecology, there

is a perceived level of authority embedded within these maps as a “scientific truth” that does act upon participants’ opinions of mosquito ecologies despite giving focus group participants a choice in maps. For example, while the focus groups concluded that these 30 m maps most accurately reflected their conceptions of mosquito areas, some participants noted that they themselves had not experienced mosquito problems in the local park. These visualizations, while uncovering perceived truths about territory, also influence the way risk is visualized and “external” spaces of risk are “internalized” in the form of anxiety. As a result, the focus group interactions *themselves* also succumbed in part to a politics of fear by re-creating a landscape of threat, or by legitimizing certain fears and generating notions of responsibility. Most important in this regard, maps that placed the highest risk in individual yards warranted calls for more resident action from local authorities. Maps that placed the highest risk in public spaces yielded calls for more state control from residents. Which map was deemed more “accurate” depended upon who was being asked and their role in mosquito control. As such, the maps themselves (coupled with investigator queries) *stimulate* calls for different types of environmental management regimes, actively participating in state-society relations.

None of this should be especially surprising, given the universally-recognized power of maps to generate and define an interpreter’s experience and reality (Crampton, 2010; Harley, 1989; Wood, 1992). Given the sensitivity of linkages people draw between notions of space (e.g. neighborhoods, “home”, etc.) and those of health and safety, the generation or re-instantiation of spatial ideas about risk in geographic research requires further scrutiny and consideration. The use of sketch mapping and other geographic techniques has been expanded in assessing fear of crime (Curtis, 2012) and a variety of health-related behaviors (Basta, Richmond, & Wiebe, 2010), which often reinforce fears of these crimes and health hazards.

These conclusions suggest the need for investigation and possible further critique of mapping itself as a part of generating new cultures of fear and responsibility.

An important limitation of this work is that it focused on the ecology of a specific mosquito, *Culex quinquefasciatus*, while there are a number of mosquito species present in Tucson. It is impossible to know exactly which mosquito species residents were referring to when they shared their experiences during the focus groups, unless they happened to be particularly well informed in mosquito identification. However, our team's trapping data demonstrated that *Ae. aegypti* and *Cx. quinquefasciatus* were the predominant mosquitoes found in central Tucson. Though there are physiological and behavioral differences between the two, both are largely urban, container dwelling species, and it is likely an *Ae. aegypti* map would have looked very similar to the map shown to residents. We chose to focus on *Cx. quinquefasciatus* for this work because it is the predominant vector of West Nile virus, which remains a concern in Arizona. Further work might try to flesh out how ecological understandings of multiple mosquitoes with differing habitats and behaviors are perceived and acted upon by residents.

6. Conclusion: Visualization as a Tool for Political Ecology

Recent work within a political ecology framework has contributed to a broader conversation of how vector control is practiced within and across institutions (xxx, 2008, masked for blind review; xxx, 2012; xxx, 2010; Tedesco, Ruiz, & McLafferty, 2010). The case of visualizations of an urban mosquito in Tucson contributes to such discussions by demonstrating the utility of this type of approach for political ecological research. By presenting multiple groups with different displays of the same data, we were able to delve into ecological and territorial understandings of mosquito habitat not accessible in previous work using survey

methods (xxx n.d., in review). The use of these visualizations after conducting neighborhood surveys illustrates that certain kinds of politics are only apparent (or at least more easily investigated or observed) through the use of visualizations. In this case, the investigation called to attention the differential and competing notions of responsibility and authority over specific private or public spaces, between local residents and state agents. Further, the divergent responses produced by the maps but not captured by the surveys provide insight into the power of spatial representations as a form of reality or truth. The politics of responsibility is therefore linked with, and perhaps prior to, assumptions or perception biases about ecological systems. Different notions of mosquito ecology are tied to competing notions of territorial responsibility. Therefore, we are reminded that MAUP it is not simply a problem of data aggregated in a fictitious or deceitful way. Rather, all scales are called into question.

Inherent to this work is a concern for how ecological data are displayed, understood, and ultimately acted upon. The distortion of maps and spatial data for political purposes has been extensively studied in geography (Monmonier, 1996; Wood, 1992), and all maps and models are oversimplifications. It is this point that we believe makes this a useful visualization technique for political ecologists interested in understanding issues of territory and spaces, as such scholars are well attuned to the role maps and statistical representations of the environment play in ecological governance strategies. Arun Agrawal (2005) argues: “statistics, maps, numerical tables, and their collation in specific formats can become the basis for producing new forms of knowledge that make some actions seem naturally more appropriate in comparison to others as an invaluable aid to the process of government.” In our research, county health officials responded most strongly to maps that reflected the vector control work that they do: encouragement of private management of scattered, small mosquito sources in yards. This

critical lens as applied to the use of geospatial modeling provides a space for important reflexive consideration of the type of work maps do, especially in research and environmental management processes. While we recognize the utility, limitations, and problems associated with this type of approach to human-environment questions, we also see this approach as able to generate new and unique ways of thinking through schisms, convergent, and divergent views of environmental governance. Geospatial tools and visualization open possibilities of both fear and hope (Klinkenberg, 2007). The use of visualizations pairing quantitative and qualitative techniques offers new tools to an eclectic political ecology “toolkit” (Watts & Peet, 2004), which can be engaged in more critical conversations of political ecology praxis (Walker, 2007).

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Table 1. Reported West Nile Virus Cases in Arizona and the United States, 2003-2013.

737 Table 1. Reported West Nile Virus Cases in Arizona and the United States, 2003-2013.

Year	Pima County Cases ^a	Pima County Cases per 100,000 ^b	Arizona Cases ^c	Arizona Deaths ^c	Arizona Cases Per 100,000 ^b	US Cases ^c	US Deaths ^c	US Cases Per 100,000 ^d
2003	2	0.22	13	1	0.23	9,862	264	3.40
2004	7	0.77	391	16	6.83	2,539	100	0.87
2005	16	1.70	113	5	1.91	3,000	119	1.02
2006	47	4.90	150	11	2.45	4,269	177	1.43
2007	15	1.53	97	6	1.55	3,630	124	1.21
2008	13	1.32	114	7	1.79	1,356	44	0.45
2009	0	0	20	0	0.31	720	32	0.23
2010	12	1.22	167	15	2.61	1,021	57	0.33
2011	19	1.93	69	4	1.07	712	43	0.23
2012	33	3.33	133	7	2.05	5,674	286	1.81
2013	2	0.20	62	6	0.94	2,469	119	0.78

738 ^a Case reports as of August 25, 2014. United States Geological Survey 2014,
 739 <http://diseasemaps.usgs.gov/wnv_az_human.html>. Accessed August 25, 2014.

740 ^b Based on the Arizona Department of Administration intercensal estimates, <
 741 <https://population.az.gov/population-estimates>>. Accessed August 25, 2014.

742 ^c Case reports as of August 25, 2014. United States Center for Disease Control 2014,
 743 <http://www.cdc.gov/ncidod/dybid/westnile/surv&controlCaseCount12_detailed.htm>.
 744 Accessed August 25, 2014.

745 ^d Based on the US Census Bureau Population Division intercensal estimates, for 2000-2009
 746 <<http://www.census.gov/popest/data/intercensal/index.html>> and 2010-2013
 747 <<http://www.census.gov/popest/data/national/totals/2013/index.html>> . Accessed August 25,
 748 2014

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752 Figure 2. Modeled risk of seasonal presence in Cholla Vista at 1 m resolution.

753 Figure 3. Modeled risk of seasonal presence in Tucson at 30 m resolution.

754 Figure 4. Modeled risk of seasonal presence in Cholla Vista at 30 m resolution.

Figure 1

Risk of Presence

Figure 2

Risk of Presence

Figure 3

Risk of Presence

Figure 4

Risk of Presence