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Mapping in and out of "messes": An adaptive, participatory, and transdisciplinary approach to assessing cumulative environmental justice impacts

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1. Introduction

A primary concern of environmental justice scholarship, policy, and social movement organizing is addressing the disproportionate impacts of environmental hazards and restricted access to environmental goods experienced by people of color and low-income people (Cole & Foster 2001; Pulido 1996; Sze & London 2008). The experience of environmental injustices by these, and other, underserved populations, combined with their systemic marginalization from public policy decision-making, has provoked a series of heated conflicts between environmental justice advocates, public agencies, businesses, and other social actors (Cole & Foster 2001; Pulido 1996; Sze & London 2008).

While environmental legislation and single-media regulation (e.g., the Federal Clean Air Act and Clean Water Act) have achieved tremendous success in reducing overall pollution levels, more recent efforts to identify and address disparities in the cumulative impacts on human health from multiple cross-media environmental hazards represent a new policy frontier. These approaches represent a fundamental shift from a linear cause and effect model of regulation to a more complex ecological model that considers the interconnections of biophysical and social systems (Pickett, Cadenasso & Grove 2005; Turner, et al. 2003). A cumulative impacts approach has been advocated by environmental justice activists who seek

comprehensive approaches to environmental protection that focus on the places where people live, work, play, and learn (Cole & Foster 2001). Recent academic scholarship (Huang and London 2012; Morello-Frosch et al. 2011; Sadd et al. 2011) and public policy initiatives (Alexeeff, et al. 2012; Faust 2010) have begun to conduct and systematize cumulative impacts analyses. In broad terms, cumulative impacts analysis integrates a range of environmental hazard indicators with a range of social vulnerability factors into one or more combined indices. Such indices can be used to identify populations and places that are both subject to elevated environmental hazards that also lack the economic, political, and social resources to avoid, mitigate, or adapt to these impacts (Krieg & Faber 2004). In contrast to a formal health risk analysis, which quantifies potential health impacts of a given chemical or development project, a cumulative impacts analysis serves best as a screening tool to highlight places that require additional study, investments, and other precautionary actions (Alexeeff et al. 2012; Faust 2010).

The transition from single-media, single-location, and single point-in-time analysis to a cumulative approach represents a profound challenge – and opportunity – for policy makers, planners, advocates, and researchers. These challenges and opportunities are both social and technical. Major technical issues include limited data availability of pollution sources, uncertainty of chemical reactions among multiple pollutants, and evaluating combined health effects of multiple environmental stressors (Huang and London 2012; Krieg and Faber 2004; Morello-Frosch et al. 2011; Sadd et al. 2011). While these technical challenges have been acknowledged, systematic documentation and analysis focusing on the “wicked” or “messy”

social character (Xiang 2013) of cumulative impacts analysis is less well developed.

Underestimating this social complexity, especially in instances in which participants hold different, and even divergent world views which represent competing interests, may create unrealistic expectations that cumulative impacts problems could be eliminated merely with better data and analysis (Balint, Stewart, and Desai 2011; Fineberg and Stern 1996).

We aim to fill this gap about the understanding of the challenges and opportunities in planning, policy, and advocacy approaches to cumulative impacts through the framework of wicked problems (Xiang 2013). In particular, we argue that the wicked or messy problem of cumulative impacts requires a participatory process through which planners, researchers, and community advocates contribute their unique knowledge and develop collaborative solutions. While such an approach is unlikely to resolve the complex political, economic, social, and environmental factors that produce environmental injustice, we suggest that it can help reduce or mitigate some of the most extreme conditions.

In Section 2 we briefly introduce the framework of wicked problems and how it can help to articulate the social complexity of cumulative impacts analysis. Section 3 presents two case studies of cumulative impacts assessments in California's Eastern Coachella Valley (ECV) and San Joaquin Valley (SJV). The extreme social, political, economic, and environmental disparities in these regions of the state reflect conditions in many less-developed regions and nations and the social movements that have arisen to confront them (Agyeman 2003, Martinez-Alier 2014, Schlossberg 2013). Therefore, these cases should be of interest to

planners, policy makes, advocates, and researchers around the world. We summarize our approaches of using cumulative impacts analysis to address environmental injustices in Section 4, and conclude with reflections in Section 5.

2. Cumulative Impacts as Wicked Problem

Framing cumulative impacts as a “wicked problem” can help highlight some of the challenges and opportunities in applying this approach to addressing environmental injustices and improving collaboration between policy makers, planners, and advocates. The term “wicked problem” (Rittel & Webber 1973, 1974) or “social messes” (Horn 2001) refers to planning and design problems that defy technocratic solutions. This concept has been synthesized by Xiang (2013) to include five criteria: 1) indeterminacy in problem formulation, 2) non-definitiveness in problem solution, 3) non-solubility, 4) irreversible consequentiality, and 5) individual uniqueness.

INSERT TABLE 1: Wicked Problem Qualities and Case Study Manifestations

Cumulative impacts share these characteristics of wicked problems. First, the problem formulation of cumulative impacts is challenging because they are driven by a wide range of individual, behavioral, institutional, and structural factors. Identifying and analyzing the most significant factors and the pathways for their interactions does not follow any easily-standardized or agreed upon formula. Furthermore, assessing and acting to reduce cumulative impacts on the health of vulnerable populations and places requires active and collaborative

engagement of multiple stakeholders (e.g., policy makers, advocates, business interests) that are often at odds with each other. Second, conflicting problem definitions make solutions to avoid or mitigate such complex and incompletely understood impacts difficult to identify and agree upon. Third, the lack of agreement on a non-arbitrary “stopping point” for identifying relevant indicators, collecting data, and analyzing results impedes the ability for policy makers and planners to shift decisively from tool development to implementation in planning and policy. Fourth, any approach to address the complex systems of cumulative impacts can themselves have unintended, negative, and possibly irreversible consequences. Finally, cumulative impacts analysis must be place-specific to account for unique characteristics, while still conforming to accepted standards of scientific rigor and regulatory frameworks.

We argue that the wickedness of cumulative impacts is a function of the complex experiences of overlapping environmental and social hazards experienced by vulnerable communities, which in turn, requires a complex policy and advocacy response. Recent scholarship on wicked problems has suggested that strategies to navigate, if not solve, wicked problems require adaptive, participatory, and transdisciplinary approaches (Xiang 2013) and deliberative social learning processes (Balint, Stewart, and Desai 2011; Fineberg and Stern 1996). We assert that if cumulative impacts analysis is conducted in this adaptive, participatory, and transdisciplinary manner, it can address many of the wicked problem characteristics outlined above. In particular, such an approach to cumulative impacts analysis requires spanning scientific cultures (e.g., natural, health, social sciences) and integrating formal research science with the “street science” developed by communities through their

lived experiences in place- and community-based participatory research (Brown, Morello-Frosch, & Zavestoski 2011; Corburn 2005; Liévanos, London, Sze, Ottinger & Cohen 2010).

In the two case studies that follow, we describe how a research team worked with a diverse range of community partners to document and intervene in the production of cumulative environmental impacts. These partners used adaptive, participatory, and transdisciplinary approaches (Xiang 2013), including socio-spatial mapping and public participatory geographic information system (PPGIS) to confront the wicked nature of cumulative impacts.

3. Cumulative Impact Assessment Innovations in California's Eastern Coachella Valley and San Joaquin Valley

California has been a leader in assessing cumulative impacts, with applied research academic teams (Evans and Marcynyszyn 2004; Huang and London 2012; Morello-Frosch et al. 2011; Sadd et al. 2011), public agencies (Alexeeff et al. 2012; Faust 2010), and community advocates developing these collaborative approaches. California therefore presents a rich opportunity to document and learn from these early adoption experiences.

INSERT FIGURE 1: Case Study Areas: The Eastern Coachella Valley and San Joaquin Valley of California

Both the Eastern Coachella Valley (ECV) and San Joaquin Valley (SJV) are inland regions that are typically relegated back stage to the iconic cities and landscapes of California's

golden coast. Yet, these regions generate a large share of the state's economic wealth.

Moreover, their residents shoulder much of California's cumulative environmental burdens, and suffer from high levels of poverty and other social vulnerability factors (Cole & Foster 2001; Fujimoto 2010; Martin & Taylor 1998).

3.1 The Eastern Coachella Valley

Regional Context

The Coachella Valley, in southern California's Inland Empire, is a land of stark contrasts. The lush golf courses, exclusive resorts, and celebrity sightings of the iconic Western Coachella Valley communities such as Palm Springs are worlds apart from the unpaved streets, failing septic systems, and unauthorized waste dumps of the ECV. The vast majority of the approximately 90,000 ECV residents live in highly ethnically- and racially-segregated communities with low levels of economic resources. For example, in the ECV, 94% of residents are people of color (the majority being Hispanic, with a large proportion of indigenous Mexicans as well as members of several Native Americans tribes); 45% have limited English proficiency; 65% live below the federal poverty line; and 14% are unemployed (United States Census Bureau 2013). A labor market dominated by low-paying agricultural and hospitality jobs drives much of this economic deprivation (Ramirez & Villarejo 2012). Residents of the ECV also contend with a lack of affordable, safe, and quality housing, limited public transit, high levels of agricultural pesticide use, drinking water contamination, and concentrations of toxic and hazardous industrial facilities (London,

Greenfield & Zagofsky 2013; Ostro, Hurley & Lipsett 1999; Ramirez & Villarejo 2012; Villarejo, et al. 2000).

Community and regional advocacy organizations in the ECV that are focused on environmental health and justice have been mobilizing for decades to empower residents to depict their environment as an inequitable environmental justice "riskscape" (Morello-Frosch & Lopez 2006). While many of these organizations have similar goals, their ability to collaborate is often limited by disparities in access to funding, and the difficulties of defining a common action agenda. In particular, during the time of this case study, conflicts over how to address the health threats from a hazardous waste processing facility generated tension between many local advocates. This divide was between those who sought to close the facility to prevent health threats to nearby residents, and those who sought to improve its operations to protect public health while maintaining local jobs and the economic welfare of the Native American tribe that leased reservation land to the waste company (Honoré 2012).

Confronting Cumulative Impacts in the ECV

In 2012, the UC Davis Center for Regional Change, directed by Jonathan London,), along with the California Institute for Rural Studies was invited by The California Endowment (a health philanthropy to develop a community-engaged participatory action research project to document the sources of environmental contamination and the populations most at risk from these hazards. The intention of the project was to support increased collaboration between regional advocates by providing a common information base to inform their strategies. The

primary community organizations in the project included farm-worker advocates such as *Lideras Campesinas*, California Rural Legal Assistance, and Leadership Council for Justice and Accountability; appropriate technology and housing assistance groups, such as *El Pueblo Unido* Community Development Corporation; faith-based organizers such as Inland Congregations United for Change; and environmental justice advocates such as *Comité Civico del Valle*.

Together with our partners, we adopted a multi-pronged approach to document the sources of environmental hazards and assess the risk of people in the ECV (London, Greenfield & Zagofsky 2013). We drew upon, and added value to, innovative practices (Alexeeff, et al. 2012; Faust 2010; Krieg and Faber 2004; Morello-Frosch, et al. 2011; Sadd, et al. 2011) to construct a Cumulative Environmental Vulnerability Assessment (CEVA) (Huang & London 2012), and adapted it to reflect the uniqueness of the region's social and environmental context. These methods helped identify places with the highest concentrations of environmental hazards and the lowest levels of social, economic, and political resources to prevent, mitigate, or adapt to these hazards. The CEVA integrates two multi-indicator indices, a Cumulative Environmental Hazard Index (CEHI), and a Social Vulnerability Index (SVI). The CEHI includes indicators on air quality, hazardous waste and solid waste facilities, waste disposal sites, air pollution, agricultural pesticide application, and drinking water contamination. The SVI includes indicators on racial and ethnic composition, income, education level, English language fluency, housing quality, and health conditions. The places with the highest levels of both CEHI and SVI are identified as Cumulative Environmental

Vulnerability Action Zones that require enhanced regulatory investments in permitting, monitoring, enforcement, public participation, and infrastructure development.

To address local environmental and social conditions in the ECV, we adapted CEVA to include regionally specific measures. For example, we developed a new process for measuring and mapping the drinking water contamination by locally prevalent pollutants (e.g., arsenic, nitrates, chromium-6) in individual and small system wells. We also selected the most toxic and exposure-prone agricultural pesticides for inclusion in the CEVA.

Furthermore, we added the locations of mobile home parks as well as tribal reservation boundaries drawing on a field-based data set developed by Professor Ryan Sinclair at Loma Linda University to more fully represent the complex social and political landscape of the region.

The project navigated the tension between the immediate need for data that could help address divisions between local advocates with the time necessary to build a common understanding and strategy for the project. To navigate this temporal mismatch, we incorporated the service of a team member with extensive expertise in group facilitation, conflict resolution, and public participation to help build a collaborative culture within the local partners, as well as between the partners and the university team. This approach required a commitment of time and resources by all parties (including the donor foundation) over and above the specific technical process of developing and applying the CEVA methodology. As will be described in Section 4 below, this initial investment provided

significant benefits in the strength of relationships between all parties, as well as a robust and locally-relevant CEVA analysis, and significant momentum in collective action on mutually-defined strategies. In particular, the project was successful in shifting attention from conflicts over one specific hazardous waste facility to a more holistic environmental justice strategy that included improved housing, drinking water, transportation, and health facilities.

The final report, *Revealing the Invisible Coachella Valley: Putting Cumulative Environmental Vulnerabilities on the Map* (London, Greenfield & Zagofsky 2013) illustrates what some local advocates refer to as the “tale of two valleys,” in which the high vulnerability of the ECV stands in stark contrast with the lower vulnerability of the WCV. Based upon the high degrees of both Cumulative Environmental Hazards and Social Vulnerability factors in the ECV, the vast majority (81%) of area residents live in places that are considered Cumulative Environmental Vulnerability Action Zones.

INSERT FIGURE 2: Cumulative Environmental Vulnerability Assessment of the Coachella Valley

The project has informed a number of action strategies that address the wicked problem of cumulative impacts in the region. One notable example was the identification of a common target of drinking water contamination in many aging mobile home parks that house many residents in the ECV. We illustrated, for the first time, the spatial distribution and severity of the problem, which helped generate greater public visibility. We also helped local partners

scale up their neighborhood-level actions to address the unincorporated status (i.e., lacking local government) of most ECV communities and the limited access to formal political representation by the many undocumented and non-English speaking residents, that together, represent shaped inequitable patterns of drinking water contamination in the region. Other actions catalyzed by the project have included: a) the launch of a door-to-door survey of health and housing conditions in ECV by the California Institute for Rural Studies and Loma Linda; b) use of the CEVA maps in campaigns by community partners to improve public transit service, affordable and quality housing, and health clinics in the area; c) integration of CEVA maps into local and regional land use planning, and d) policy advocacy to improve the state's environmental justice mapping tool (CalEnviroscreen) to better reflect local conditions and include the region as a "disadvantaged community" (OEHHA 2014). This latter success makes the ECV eligible for significant funding from California's Greenhouse Gas Reduction Fund that prioritizes investments in communities defined by CalEnviroscreen as disadvantaged (Truong 2014).

3.2. The San Joaquin Valley

Regional Context

The SJV is the southern half of California's 450-mile-long Central Valley. The SJV's total population of 4.2 million includes 46% Latino/ Hispanic residents, many of whom are first generation immigrants. While the region is well-known for its bountiful agricultural production, the poverty of the farm workers who produce this bounty, and the pollution from the region's agricultural, industrial, and goods movement sectors, are also trademarks of the

region (Fujimoto 2010; Martin & Taylor 1998; Walker 2004). The SJV accounts for 62.8% of the total pounds of agricultural pesticides used in California, resulting in significant exposure to farm workers and nearby communities (Harrison 2011). It has also been associated with some of the worst air quality (especially ozone and particulate matter) in the nation (Ngo, et al. 2010; Schwartz, Anita & Pepper 2009), as well as drinking water contamination, which is especially prevalent in small rural communities (Balazs, et al. 2011, 2012). To confront these social and environmental hazards, a vibrant environmental justice social movement grew out of generations of farm worker organizing (Cole & Foster 2001; Ganz 2009; Pulido & Peña 1998).

Confronting Cumulative Impacts in the SJV

In 2009, a coalition of environmental justice advocates approached a group of academics to conduct a collaborative study of cumulative impacts in the San Joaquin Valley. This coalition selected our research team from the UC Davis Center for Regional Change as its research partner (London, Huang & Zagofsky 2011). The coalition, called The San Joaquin Valley Cumulative Health Impacts Project (SJVCHIP), included the following partners: Fresno Metro Ministry; Center on Race, Poverty and the Environment; Medical Advocates for Healthy Air; Green Action for Health and Environment; San Joaquin Valley Latino Environmental Advancement Project; California Rural Legal Assistance; Prison Moratorium Project; Californians for Pesticide Reform; and Catholic Charities-Diocese of Stockton, among others. While these organizations had different action agendas — which varied from fighting hazardous waste facilities, to limiting pesticide use, to resisting the prison-industrial

complex — they came together to reduce cumulative impact disparities and promote environmental justice in the region. One of the common agreements among SJVCHIP members was that they were not satisfied with the ability of publically available data on pollution sources, which failed to accurately represent their lived experiences of cumulative impacts.

To address these data gaps, we worked with SJVCHIP to initiate a two-pronged strategy. The first strategy was to create a CEVA that identified the communities most heavily burdened by environmental injustices in the region (Huang & London 2012; London, Huang & Zagofsky 2011). Similar to the ECV project above, the CEVA tool integrated a wide range of environmental and social factors to identify the communities that deserved more enhanced regulatory attention and investments (Huang & London 2012a,b; London, Huang & Zagofsky 2011).

The second strategy was a ground-level approach using Public Participation Geographic Information Systems (PPGIS) workshops (Elwood & Ghose 2001; Elwood & Leitner 1998) to document hidden environmental hazards and social vulnerability factors defined by local residents. The university team worked with the SJVCHIP to host five PPGIS workshops throughout the region. The PPGIS workshop in West Fresno, an urban neighborhood with a majority of low-income people of color who contend with high concentrations of environmental hazards, illustrated how the SJVCHIP coalition used this process to address the wicked problems of cumulative impacts. In particular, the PPGIS workshop in West

Fresno helped build trust among all parties, facilitated open discussion to generate shared knowledge, and strategically presented this knowledge to influence local and regional land use and environmental planning.

Before the PPGIS workshops, our research team facilitated capacity-building workshops with SJVCHIP members on how to use maps to illustrate cumulative environmental health impacts. Through this process, we reached agreements with participants on a range of parameters, including selecting the data sets, defining enumeration units, and determining legend design and color scales. Based upon these agreements, we produced a series of maps that documented a wide range of environmental hazards, including source pollution sites, pesticide applications, air quality conditions, as well as social vulnerability factors such as poverty, limited formal education, limited English fluency, and racial segregation. We shared these maps with participants before the workshop (Table 2).

INSERT TABLE 2: Datasets and Maps Prepared for the Fresno PPGIS Workshop

The PPGIS workshop itself in West Fresno was organized into three steps. The university team worked with SJVCHIP partners to develop the workshop agenda based upon their knowledge of the local cultures and community concerns. SJVCHIP members invited local leaders to participate. On the day of the workshop, there were 23 participants — many of whom were from a local organization called Concerned Citizens of West Fresno — who had been advocating for many years for the city to clean up and reinvest in their neighborhood.

Participants were divided into three groups based upon area of residence in the neighborhood. Each group was given a high resolution satellite image (1 meter pixel), with major street names, landmarks, and pollution sites identified in publically-available datasets. First, as a warm-up exercise, people were asked to locate their homes on the map using major streets and landmarks to orient themselves. People were also encouraged to add more street names and landmarks on the map, to help them more easily locate themselves and feel more comfortable at drawing on the maps. The participants were then asked to identify the locations and kinds of pollution sites and discuss their experiences with these pollution sources. For the final activity, we gave them two assignments: 1) add other pollution sources not included in public agency data by marking the locations and significance of sites on the map, and 2) discuss what actions are needed to address environmental injustices in West Fresno. Each group reported their answers back to the entire audience. Maps and notes were collected at the end of the workshop.

Following the workshop, the university team digitalized the sites of pollution sources identified by residents, and included captions based upon the annotations made by the residents on the maps. The team then sent them back to the participants for review. Based upon feedback from the participants, the team further refined the maps and captions, and sent them for another round of review. After several rounds of editing, the researchers generated a rich dataset and series of maps of cumulative impacts that integrated publically-available data with the local knowledge and concerns of area residents (See Figure 3).

INSERT FIGURE 3: Participatory GIS Map of Community-Identified Environmental Hazards

Outcomes

The PPGIS workshops attempted to address the wicked or messy character of environmental injustice that often defies technocratic problem and solution definitions. Indeed, integration of vastly different sources of data and ways of knowing in the public and community-generated knowledge domains made these maps “messy.” However, it was only through such a mash up of knowledge types and mapping conventions that the wicked character of cumulative impacts could be accurately represented. As noted by Balint et al. (2011), a networked learning approach is necessary in situations in which participants with diverse and divergent world views and values are seeking to collaborate. The process to design and implement the PPGIS workshop helped to build trust among researchers, SJVCHIP, and local organizations. In particular, by respecting and legitimating community knowledge, the process helped heal some of the history of distrust of the university that many advocates saw as more responsive to big business than to disadvantaged communities (Friedland 2010; Taylor 1976).

During the process, participants also realized that they often used the same words, but with different meaning than their own neighbors. For example, the word “pollution” may mean a pile of garbage for one person, and barking dogs for another. In other cases, an “empty field” that went unmarked by one resident was identified as a hazard based upon their knowledge

that children often played near an informal waste dump on the lot. By locating all of the pollution sources on the map and discussing their relevance in their own lives, residents came to perceive larger patterns of cumulative impacts that were otherwise hard to describe. During the iterative editing process after the workshop, participants reached agreement about what should be identified as a pollution source, and therefore generated a shared knowledge base for future collaborative action. While participants initially came in with individual objectives from different local organizations, the PPGIS workshop and its products supported a vision of moving toward a common future. The university team provided all of the digital maps to the community partner organizations and extended an invitation for requests to reproduce or revise maps as needed.

In the years since the publication of the report, we have continued to collaborate with many of the SJVCHIP organizations on a range of environmental justice-related projects.

Environmental justice advocates have used the CEVA maps to inform their strategies to influence regional transportation, housing, and land use plans (Karner et al. 2014). At the local scale, residents and environmental justice advocates have used the PPGIS maps to pressure the Fresno City Council to reconsider its permitting of noxious facilities in West Fresno (Figure 4). One community leader with Concerned Citizens of West Fresno, the host organization for the PPGIS workshop, described the impacts of the maps as helping their organization “confront the powers that be so we can build the power to be.”

INSERT FIGURE 4: Residents Use a PPGIS-generated Map for Neighborhood

Advocacy

4. Discussion: Success Factors in Addressing Cumulative Impacts as Wicked Problems

While the CEVA projects in the ECV and SJV involved a range of analytical innovations, the most critical strategy to address the wicked problem of cumulative impacts was the participatory, iterative, and adaptive process that engaged the researchers in dynamic collaboration with a diverse array of local partners (Xiang 2013). The social process utilized to address these wicked qualities of cumulative impacts through these CEVA projects are summarized in Table 3.

INSERT TABLE 3: Project Responses to Wicked Problems

Before detailing the strategies to these specific wicked characteristics, however, it is important to distinguish the overarching tenet of the projects' approach; namely, the two projects started slow to go fast. Despite time pressures to create a final product, we built in significant time and attention for the “forming, norming, storming, and performing” phases of the partnership group (Tuckman 1977) that were needed to promote adaptive, participatory, and transdisciplinary approaches (Xiang 2013). The project team invested in hiring a skilled facilitator with expertise in group dynamics, conflict resolution, inter-cultural communication, and collaboration to guide a deliberative learning process (Balint, Stewart, and Desai 2011). In addition to facilitating the interactions between the researchers and

community partners (including extensive one-on-one meetings, phone calls, and email correspondence to gather input and feedback on the cumulative impacts methodology, analysis, and documentation), this staff person also played key roles in assisting the local partners to establish a functional collaboration, including developing a mission statement, organizational structure, collaboration ground rules, and a common action plan.

While valuable, it is also appropriate to question whether this active involvement may have strayed outside the bounds of an academic approach, or may have impinged on local partners' own capacity-building. In this case, we believed that had the researchers restricted their role to the typical academic functions of designing and implementing the cumulative impacts methods, it is unlikely that the project could have achieved its intended results of scientific innovation and community impact (London, et al. 2013; Nyden 2005; Reardon 1995). Even as the team built its understanding of local cultures, relationships, and histories, it also worked to maintain "cultural humility," (Tervalon & Murray-Garcia 1998) or the on-going process of learning about people of different cultures that seeks mutually respectful relationships, as opposed to mastery of a set of cultural facts about the other.

The collaborative learning process included making all of the maps available to the community partners in paper and digital form, and as part of a policy report designed to inform community planning, organizing, and self-empowerment. An agreement on data sharing and ownership was formalized in the SJV project through a Memorandum of Understanding between the research team and the SJVCHIP organizations (London, Huang &

Zagofsky 2011) with similar though informal agreements in the ECV. The reports coupled sophisticated socio-spatial analysis with qualitative cases of problems and potential solutions written in non-academic language and illustrated by photographs contributed by the community partners. We also presented the report in a series of press events, conferences, and media interviews conducted together with community partners. In many cases, these events involved collaborative presentations by both the researchers and the community partners, signaling a democratic relationship between academic and local knowledge. For example, one community event in the ECV was held primarily in Spanish and featured farm workers and other residents speaking about how they experienced cumulative impacts in their lives and what kinds of actions they demanded to improve their health and well-being. Other events included presentations to regional, state, and federal agencies to promote the application of CEVA to reducing environmental injustices. This democratic approach to our project defined the social process utilized to address the wicked qualities of cumulative impacts, which are described in detail below.

4.1 Indeterminacy in Problem Formulation

We recognized the value of multiple sources of knowledge and ways of knowing, and developed a project design that drew upon the unique insights and expertise from researchers and community partners. This collaborative approach to defining the problem was imperative because of the complexity of cumulative impacts, and because of the researchers' limited initial knowledge about the social, cultural, and political dynamics of the region. Placing local knowledge at the center of the project was critical to ensuring that the project met local

needs and aspirations. Highlighting local knowledge was also crucial to align with one of the principles of environmental justice, which recognizes that communities must be able to “speak for ourselves,” thereby signifying the self-empowerment that comes with self-representation, and the wisdom that derives from lived experiences of environmental injustices (Cole & Foster 2001).

Valorizing local knowledge did not mean excluding other sources of information and analysis, such as that offered by a university-based research team. In fact, community partners viewed an academic approach as offering a level of rigor and of academic legitimacy that could complement their local knowledge. Instead of an either/or zero-sum model of knowledge, the power of the projects was found in the rich interactions and encoding of these knowledge strands in the final map and data products. This took shape in the final reports that combined maps produced by researchers in partnership with the community leaders who helped define the most relevant indicators, scale, and boundaries of the maps, as well as helped develop narratives and photographs highlighting the most pressing manifestations of the patterns indicated on the maps.

4.2 Non-definitiveness in Problem Solution/Non-solubility

The projects maintained a delicate balance between what can be described as an “action research” approach, dedicated to having a positive impact on the conditions and communities being studied, and a continued openness to surprise, contradiction, and even dead-ends (Brydon-Miller, Greenwood, & Maguire 2003; Fals Borda & Rahman 1991). This moderated

the tendency for solutions-oriented research to fixate on the resolution of problems that may not have solutions, or for which proposed solutions may exacerbate the problem. We recognized that multiple historical, structural, and multi-scalar forces drove the patterns of cumulative impacts, many of which were not amenable to change by a project with temporal, spatial, and resource limitations. Therefore, we did not set ourselves the goal of solving this problem, but rather of developing knowledge products (e.g., maps, spatial analysis, synthesis reports) to build a more comprehensive, critical, and shared understanding of the problems to enable local partners to devise their own action strategies to effect change over time.

4.3 Irreversible Consequentiality

Strategies to address the complex systems of cumulative impacts can themselves have unintended, negative, and possibly irreversible consequences. While cumulative impacts analysis does operate in an iterative fashion, it is not completely open-ended, and does require closure — if only temporarily — to enable the analysis and mapping to proceed. Similarly, not closing the iterative loop could interfere with goals of influencing public policy, which needs some definitive basis for decision-making. However, closing this loop does have consequences for the ability of the cumulative impacts to reflect local conditions and serve as a collective learning process. Despite its foundational value of democratizing knowledge and integrating academic and community ways of knowing, it is also a highly complex methodology that cannot avoid partially obscuring its inner workings from non-technical parties. This can put community members and many policy makers without specialized training at a disadvantage to understand and apply the tools. This dynamic can

become exacerbated as the method becomes increasingly complex to better respond to community interests in representing their lived realities. The university team addressed this by making their method explicit and open to scrutiny throughout the process.

4.4 Individual Uniqueness

Cumulative impacts analysis is particularly valuable in cases where the specific cause of health impacts is complex and uncertain, and therefore not easily fit into existing analytical or policy models (Alexeeff et al. 2012; Faust 2010b; Morello-Frosch et al. 2011). This approach provides the basis for community leaders to represent and communicate the wide variety of threats to their health and well-being in ways that single-issue frameworks, which focus on one contaminant or medium (e.g., air, water, soil), cannot. Similarly, cumulative impacts analysis can respond to the need to address the interactions between multiple social and environmental factors. In these cases, an experimental or step-wise inquiry process, coupled with the gathering of multiple forms of knowledge from researchers and community experts, is necessary. Incorporating information derived from diverse scientific disciplines and ways of knowing can provoke questions, problem statements, and possible solutions that could not be foreseen from the vantage point of any one methodological perspective.

5. Conclusions

With increasing academic attention on cumulative impacts analysis, many of the technical, methodological challenges have been specified and addressed. In contrast, the social challenge, as we summarized through the framework of wicked problems, has been less well-

theorized and studied. The two case studies illustrated approaches to addressing the wickedness or messiness of cumulative impacts and cumulative impacts analysis. Our approach that combined the multi-indicator CEVA index, PPGIS workshops, and facilitated collective learning processes provided productive ways to navigate our ways through the messes of wicked problems. Although our cases focused on cumulative analysis in the U.S., we argue that both the framework of wicked problems and a corresponding participatory approach are relevant, and can provide reference to environmental researchers and practitioners worldwide. For example, severe air pollution in developing countries (such as China and India) has drawn attention from researchers, grassroots organizations, and the public (e.g., Huang 2015). Global environmental justice social movements (Agyeman 2003, 2014; Martinez-Alier 2014, Schlossberg 2013) are likewise using science in novel ways to analyze these problems at multiple scales linking academic with civic actors in collaborative partnerships. Our experience to apply wicked problem framework would also benefit their public participatory efforts on integrating local knowledge with official monitoring data, as well as working with multiple objectives. Research on how these approaches would work in vastly different political, economic, social, cultural, and environmental contexts will be necessary to develop effective place-based cumulative impacts analysis methodologies.

For researchers, maintaining both humility and a commitment to presenting the complex factors that produce cumulative environmental vulnerability in a publically accessible way can help avoid the imposition of simplified models over complex community realities.

Building the capacity of community and policy users to effectively interact with these tools

(i.e., identifying the initiatory problem, informing the selection of indicators, contributing to the analysis of the socio-spatial patterns, designing the presentation and communication of the final results) can both improve the method, and increase community self-empowerment as agents — not mere subjects — of this approach. This, in turn, demands new forms of partnerships between researchers, community partners, and policy leaders based upon mutual respect and co-learning. Using cumulative impacts analysis can help to forge new pathways and partnerships through this messy terrain towards more just environmental and social conditions for the most vulnerable populations.

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Table 1. Wicked Problem Qualities and Cumulative Impacts Manifestations

<i>Wicked Problem Quality</i>	<i>Manifestation in Cumulative Impacts Analysis</i>
Indeterminacy in problem formulation	Assessing cumulative impacts involves multiple stakeholders, who define pollution sources and health implications from different perspectives. It is extremely hard, if not impossible, to achieve consensus on what factors should be considered.
Non-definitiveness in problem solution	There are ways to mitigate negative impacts from multiple environmental hazards and social vulnerability, but every approach will have an impact itself and many cannot be fully predicted.
Non-solubility	Cumulative environmental and social impacts can be reduced but not eliminated. There is no one course of action could completely solve all the interlinked aspects of the problem.
Irreversible consequentiality	Any approach to mitigate cumulative impacts will have ripple effects in the communities that are “neither reversible nor stoppable” (Xiang 2013).
Individual uniqueness	In each geographic area or for each specific population, assessing cumulative impacts represents a distinct problem requiring unique solutions.

Table 2 Datasets and Maps Prepared for the Fresno PPGIS Workshop

<i>Datasets</i>		<i>Maps</i>
Point source pollution sites (U.S. EPA 2006)	Toxic release inventory (TRI) sites	TRI sites and people of color
	Refineries	TRI sites and poverty rate
	Hazardous waste treatment, storage and disposal facilities	Point source pollution and poverty rate
	Chrome platters	Point source pollution sites over satellite image base map
Pesticides (CA Dept. of Pesticide Regulation 2007)	Total amount ag. pesticide application per 1 sq. mile	Ag. pesticides applications by census block group
Cancer Risk from Air toxics (U.S. EPA 2002)	National-scale air toxic assessment (NATA)	Census block group maps
Demographic info (Census 2002)	Percent of linguistically isolated households	Census block group maps for each variable and a combined Social Vulnerability Index
	Percent of population in poverty	
	Percent of people of color	
	Percent of people older than 25 without a high school diploma	

Table 3 Project Responses to Wicked Problems

<i>Wicked Problem Quality</i>	<i>Manifestation in Cumulative Impacts Analysis</i>	<i>Project Responses</i>
Indeterminacy in problem formulation	Assessing cumulative impacts involves multiple stakeholders, who define pollution sources and health implications from different perspectives. It is extremely hard, if not impossible, to achieve consensus on what factors should be considered.	Promote active engagement with a diverse range of stakeholders to define cumulative impact problems in multiple ways. - The CEVA approach in both cases accounted for multiple pollution sources of concern to advocates. - The PPGIS workshops in the SJV provided opportunities for grassroots residents to collaboratively define problems not visible through public data.
Non-definitiveness in problem solution	There are ways to mitigate negative impacts from multiple environmental hazards and social vulnerability, but every approach will have an impact itself and many cannot be fully predicted.	Avoid pre-determining the solutions, and allow these to emerge through engagement of all parties. - The ECV project did not seek to solve the immediate conflict over a local hazardous waste site, but instead expanded the solution set to include win-win options (e.g., improvements to affordable housing with clean drinking water).
Non-solubility	Cumulative environmental and social impacts can be reduced but not eliminated. There is no one course of action that could completely solve all the interlinked aspects of the problem.	Aim to stimulate and facilitate positive change and allow for multiple imperfect or “messy” solutions that can evolve over time. - Both projects informed state and federal environmental and health protection policies that could identify areas in need of investments. Advocates continue to push for public agency action to address cumulative impacts and reduce environmental injustices.
Irreversible consequentiality	Any approach to mitigate cumulative impacts will have ripple effects in the communities that are neither reversible nor stoppable	The engagement of EJ advocates in the ECV and SJV in CEVA projects represent significant commitments of time and financial commitments by local partners that have reduced available resources for other issues.

<p>Individual uniqueness</p>	<p>In each geographic area or for each specific population, assessing cumulative impacts represents a distinct problem requiring unique solutions.</p>	<p>The CEVA projects drew upon best practices but tailored the approach to the unique regional contexts.</p> <ul style="list-style-type: none"> - In the ECV drinking water contamination and affordable housing were integrated into the CEVA to respond to priorities of advocates - In the SJV the PPGIS workshops allowed residents and advocates to enhance public data with local knowledge about hidden hazards.
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