

THE ECOLOGY OF GANG TERRITORIAL BOUNDARIES*

P. JEFFREY BRANTINGHAM

Department of Anthropology
UCLA

GEORGE E. TITA

Department of Criminology, Law and Society
University of California—Irvine

MARTIN B. SHORT

Department of Mathematics
UCLA

SHANNON E. REID

Department of Criminology, Law and Society
University of California—Irvine

KEYWORDS: ecology, spatial analysis, mathematical modeling, street gangs, violent crime

Within any type of system, the actors in the system inevitably compete over resources. With competition comes the possibility of conflict. To minimize such effects, actors often will partition the system into geographic territories. It is against the larger ecological backdrop of competition and conflict that we examine territory formation among urban street gangs. Although previous studies have examined the social and built environment where gangs form, and how the presence of a gang influences local levels of violence, we know little about how competitive interactions are tied to the formation and maintenance of gang territories. We use formal spatial Lotka–Volterra competition models to derive hypotheses about competition-driven territory formation. By using data

* We would like to thank the four anonymous referees for their helpful suggestions. This work was supported by grants NSF-FRG DMS-0968309, ONR N000141010221, ARO-MURI W911NF-11-1-0332, and AFOSR-MURI FA9550-10-1-0569. Direct correspondence to P. Jeffrey Brantingham, Department of Anthropology, University of California, 341 Haines Hall, Los Angeles, CA 90095 (e-mail: branting@ucla.edu).

on 563 between-gang shootings, involving 13 rival street gangs in the Hollenbeck Policing Division of Los Angeles, we show that violence strongly clusters along the boundaries between gangs in a way that is quantitatively predicted by the theory. The results suggest that even weak competitive interactions between gangs are sufficient to drive gang territory formation without recourse to other processes or assumptions.

Competition is a mainstay of social and ecological systems, and the manner in which competition plays out has important geographic dimensions to it. On the one hand, geographic boundaries and territoriality may serve to rein in competition, keeping it from erupting into open conflict. Individuals or groups may exploit existing physical barriers as natural boundaries (Eason, Cobbs, and Trinca, 1999), or if none are available, they may draw imaginary boundaries to self-segregate. Boundaries emerge within the home (Ahrentzen, 1990), prisons (Sibley and Van Hoven, 2009), cities (Olzak, 1994), and both within and between nation-states (Donnan and Wilson, 1999), and all such boundaries are implicated in reducing violence. On the other hand, geographic boundaries also may serve as a source of conflict. Most armed conflicts occur among neighboring states. Most conflicts also grow out of low-level border disputes (Senese and Vasquez, 2003; Vasquez and Henehan, 2001). Whereas conflict can be costly, the benefits gained from defending boundaries, and thus maintaining greater rights to resources, can be significant.

There is every reason to suppose that criminal street gangs qualitatively replicate these connections between territoriality and conflict. Numerous studies demonstrate the primacy of “place” in shaping the identity of the gang as a social group (Cartwright and Howard, 1966; Klein, 1995; Maxson, 2011; Thrasher, 1927; Tita, Cohen, and Engberg, 2005). Place also plays an important role in shaping the violence committed by gang members, especially against rival gangs (Griffiths and Chavez, 2004; Rosenfeld, Bray, and Egley, 1999; Tita and Ridgeway, 2007). More recently, researchers have begun to look at how social ties (rivalry) among gangs shape the patterns and levels of violence (Greenbaum and Tita, 2004; Papachristos, 2009; Radil, Flint, and Tita, 2010). Although territoriality and violence are defining features of urban street gangs, the influence of intergang competition on the creation and maintenance of boundaries between gangs has received limited attention. The present article aims to address this lacuna within the place, conflict, and urban street gang literature by combining perspectives drawn from theoretical ecology with empirical data on the spatial characteristics of gang violence.

We begin by examining the types of resources over which urban street gangs, and their members, compete. We then use a formal mathematical model—specifically a spatial Lotka–Volterra competition model—as a

framework linking between-gang competitive interactions to the formation of gang territories (see Case et al., 2005; Case and Taper, 2000; Cosner and Lazer, 1984). The theoretical framework relies on the notion that the processes embodied in a simple, explicit mathematical model of a phenomenon are sufficient to produce that phenomenon. If the predictions of the model match empirical data, then the modeled processes are taken to provide a plausible account of the phenomenon, without recourse to other processes or assumptions. Consistency of empirical data with model predictions does not, of course, rule out the possibility that other processes or assumptions might be part of an alternative plausible explanation. Nor does empirical consistency purport to explain phenomenon not specified by the model.

In the present case, the theory originating from the Lotka–Volterra competition equations suggests that competition *between* rival gangs, as long as it is stronger than competition *within* gangs, may be responsible for the fact that criminal street gangs form stable territories. We explore the impact of varying the strength of competition between gangs and derive specific predictions about the spatial distribution of gang violence in relation to theoretically predicted boundary locations. Empirical data on between-gang violence among 13 criminal street gangs in the Hollenbeck Policing Division of Los Angeles are used to demonstrate that violence strongly clusters along the boundaries between gangs as predicted by theory. The estimated strength of competition between gangs is greater than that estimated to be occurring within gangs, an observation that also is consistent with the theory. However, it is only marginally greater, making it hard to characterize between-gang violence as extreme. We conclude by discussing several counterintuitive implications the analyses hold for policing gang violence. In particular, the model suggested that attempting to dampen gang rivalries may have the unintended consequence of driving up between-gang violence.

GANGS, RESOURCES, AND TERRITORIALITY

Gangs are thought to provide their members with resources, such as money, employment, protection, and social control that legal institutions are unable to provide (Hagedorn, 1988; Klein, 1995; Maxson, 1995; Spergel et al., 1996). But, in the absence of these legal institutions, violence and the threat of violence may drive the allocation of scarce resources (Donohue and Levitt, 1998). Which resources a gang can provide, and which they are willing to fight over, may vary across settings, with some gangs focusing on economic gain and others on protection. Qualitative studies have explored how a gang's criminal enterprises offer economic opportunities for local

residents, thereby embedding gangs into the social and economic fabric of the neighborhood (Sanchez-Jankowski, 1991; Sullivan, 1989; Venkatesh, 1997). Sutter (1995) found that the ease with which an individual can exit a gang, to either join another gang or withdraw from gang membership altogether, affects whether the gang is overly predatory or primarily provides protection services to gang members. Patillo-McCoy (1999) has examined the dual roles of gang members as family and friends of local residents, and she has posited that gangs are sources of stability within a community. Gang membership also has been shown to provide interpersonal resources such as friendship, status, and respect for young men (Anderson, 1999; Decker and Van Winkle, 1996; Fleisher, 1998). In a study of gangs in Chicago, Block and Block (1993: 8) found that “gangs specializing in instrumental [economic] violence are strongest in disrupted and declining neighborhoods,” whereas “gangs specializing in expressive [interpersonal] violence [are] strongest and most violent in relatively prospering neighborhoods with expanding populations.”

Space is also an important resource for gangs. Earlier work on gang territoriality focused on the gang as an organization that grows out of informal neighborhood play groups (Thrasher, 1927). This concept of naturally emerging territoriality has been supported by several gang researchers. Moore (1978: 35), when studying Los Angeles Chicano gangs, noted that “the word for gang and for neighborhood is identical. ‘Mi barrio’ refers equally to ‘my gang’ and ‘my neighborhood.’” When studying New York street gangs, Campbell (1984: 286) found that gang violence “is one neighborhood against another, as the gangs see it. . . . Gangs remain neighborhood-based.” More recent studies have expanded the idea of territoriality so that gang territory may be a separate space from gang member residence. Increased mobility and the influence of school busing have weakened the connection between residency and gang territory (Decker and Van Winkle, 1996; Hagedorn, 1988). Moving away from a gang territory does not necessarily mean removal from the gang. Moore, Vigil, and Garcia (1983) found that, as a result of frequent relocation of gang members, territory and residence may be two separate areas but allegiance to the neighborhood gang remains strong.

Whereas gangs may claim ownership of wide territorial regions, it also is clear that the actual activities of gang members concentrate in certain restricted locales. Accordingly, gang set space is defined as “the actual area within the neighborhood where gang members come together as a gang” (Tita, Cohen, and Engberg, 2005: 280). Gang members congregate for social and economic purposes and need an identifiable space for this activity. Set spaces tend to appear on street corners (Liebow, 1967; Werthman and Piliavin, 1967; Whyte, 1955), the position of which allows gang members to monitor the coming and going of pedestrians and vehicles,

while reducing the level of surveillance of their own activities by mid-block residents (Taylor and Brower, 1985). Abandoned spaces such as buildings or vacant lots may provide similar cover for the gang. Control of a corner or vacant lot may allow for drug transactions to occur with little risk of interference, and a large enough volume of drug sales may transform a street corner into an open-air drug market (Harocopos and Hough, 2005; Rengert, 1996). A gang that is heavily invested in the drug trade may actively defend its space to prove that it belongs to the gang (Eck, 1994), especially because a valuable street corner may be intimately linked to the prestige of the gang (Ley and Cybriwsky, 1974). Taniguchi, Ratcliffe, and Taylor (2011) found that, in accord with territorial and economic competition models, crime levels were highest in areas where corner markets are occupied by multiple gangs.

Reputation is a resource equally important to gangs and gang members. Territories are defended in the name of the gang even where there is little or no active drug trade (Maxson, 2011). Turf battles in such contexts are intimately tied to efforts to build, maintain, or restore the reputation of both individual gang members and the gang as an institution. An attack across gang lines drives quick and severe retaliation (Papachristos, 2009). Retaliation by the victim is necessary to show that individuals are “down” with the gang and can handle their business. A failure to retaliate in a timely manner damages one’s reputation, and often, it leads to further attempts to take advantage of the seemingly vulnerable individual (Jacobs and Wright, 2006). A gang or gang member may lose materially in stolen drugs, property, or desirability in the eyes of members of the opposite sex if their reputation suffers (Decker and Van Winkle, 1996). One’s chance of being a victim of additional violent attacks also may go up. Less is known about the distribution and severity of within-gang violence in part because of potential reporting biases. Anecdotally at least, reputations also are likely to be built and challenged through violence occurring internal to the gang (Anderson, 1999; Bjerregaard, 2002; Decker and Van Winkle, 1996). Declining reputation may lead individuals to drop out of the gang, and extreme levels of violence (i.e., being victimized by rivals) may be enough to drive entire gangs out of an environment. Conversely, a gang or gang member stands to gain from enhanced reputation, often acquired through acts of violence. Prestige, or “street cred,” is a currency that brings with it more money, consumer goods, and attention from the opposite sex. Opportunities to increase one’s prestige may ultimately draw individuals into the gang and may, in principle, lead to the geographic expansion of the gang (Johnson et al., 2009). However, it is more common for gangs to form approximately stable distributions that are geographically quite limited and to display minimal overlap with neighboring gangs (Tita, Cohen, and Engberg, 2005).

SPATIALLY EXPLICIT LOTKA–VOLTERRA COMPETITION

We develop a spatially explicit version of the Lotka–Volterra competition model to study the relationships among gang rivalry strengths, territory formation, and the distribution of between-gang violent events. Lotka–Volterra competition models are deterministic mathematical models studied extensively in ecology (see Begon, Townsend, and Harper, 2006; Otto and Day, 2007). The classic setup for the Lotka–Volterra competition model involves two species competing with one another for limited resources in a closed environment. Given competitive strengths, initial demographic characteristics, and environmental carrying capacities, defined a priori for each species, ecologists have sought to explain the conditions under which the two species can coexist, or whether one species outcompetes the other, driving it to extinction. With the deterministic Lotka–Volterra model, these two very different outcomes can be predicted exactly from initial conditions. In other words, certain combinations of parameters will be guaranteed to produce coexistence and other combinations extinction in the context of the model. The advantage of approaching the problem from such a perspective, which we begin to leverage here, is that unambiguous predictions can be made by using deterministic models. Unambiguous predictions may lead to unambiguous tests of theory. Specifically, if observed data match model predictions, then the processes captured by the model are assumed to provide a plausible account for the observations. Alternative plausible explanations for observed phenomena may exist. However, empirical observations that fail to match quantitative predictions generally offer decisive evidence against the mechanisms as laid out in a formal mathematical model.

We model a system of two street gangs exploiting a simple, abstract urban environment. The model is easily extended to study a community of more than two rival gangs, but the implications of the model are easier to analyze for only two gangs. The current model differs from classic Lotka–Volterra competition models in two ways. First, we concentrate on modeling the density of gang-related activities, rather than on the absolute numbers or density of individuals representing different gangs (Otto and Day, 2007). This departure is possible because the Lotka–Volterra competition equations, and their constituent parts, are far more general than the strict population biology problems to which they normally are applied (see Brenig, 1988; Turchin, 2003). Second, our approach differs in being spatially explicit, forcing within- and between-gang interactions to occur locally and gang-related activities to spread or diffuse over short distances (see Case et al., 2005). We have argued elsewhere that local diffusion limitation is in fact critical to the formation of crime hotspots (Short et al., 2010). The

classic Lotka–Volterra competition model ignores space by assuming that all interactions occur globally. Let $\rho_1(s, t)$ and $\rho_2(s, t)$ be the density of gang-related activities attributed to gang 1 and gang 2 at location $s = x, y$ and time t , respectively. We are interested in how these spatial distributions of gang activities change through time and whether stationary spatial arrangements of gangs can exist.

$$\begin{aligned} \frac{d\rho_1(s, t)}{dt} &= D_1 \frac{\partial^2 \rho_1(s, t)}{\partial s^2} + r_1 \rho_1(s, t) \left[1 - \frac{\rho_1(s, t)}{K_1(s)} - \frac{\alpha_{21} \rho_2(s, t)}{K_1(s)} \right] - \gamma_1 \rho_1(s, t) \\ \frac{d\rho_2(s, t)}{dt} &= D_2 \frac{\partial^2 \rho_2(s, t)}{\partial s^2} + r_2 \rho_2(s, t) \left[1 - \frac{\rho_2(s, t)}{K_2(s)} - \frac{\alpha_{12} \rho_1(s, t)}{K_2(s)} \right] - \gamma_2 \rho_2(s, t) \end{aligned} \quad (1)$$

Equation 1 is a set of coupled partial differential equations (PDEs) that describes several unique behaviors relevant to both within- and between-gang interactions. Concentrating on the top equation, the term on the left-hand side is a time derivative that describes the rate of change in the density of gang 1 activities at location s at any instantaneous point in time t . The first term on the right-hand side describes the tendency for gang activities to spread or diffuse through space, perhaps as a by-product of gangs claiming new turf. The spread of activities occurs at a rate proportional to both D_1 , a diffusion constant, and to the local concentration (not to be confused with density) of gang activities in space $\partial^2 \rho_1(s, t) / \partial s^2$. The concentration of gang activities is a spatial derivative—note the ∂s^2 in the denominator—measuring the difference in activity densities among nearby locations. Gang activities will therefore tend to spread out from areas of high concentration to areas of low concentration. The model thus hypothesizes that gangs are naturally expansionist, pushing their activities to fill space in a complete and compact way. Nevertheless, we do not expect gangs to be able to expand indefinitely through space. Such expansionist behavior is assumed to be checked by barriers in the urban built environment (Radil, Flint, and Tita, 2010; Smith et al., 2012; Tita, Cohen, and Engberg, 2005). As we will see, competitive interactions between rival gangs also may be sufficient to restrict gang expansion.

The second term on the right-hand side of equation 1 describes the growth of gang activities in response to community conditions. Gang activities grow at a fundamental rate r_1 , which may be linked to the capacity to recruit new gang members, to existing gang members increasing their level of participation in the gang, or to the desire of gang members to increase activity in areas already under their control. In the absence of other constraints, gang activities would grow exponentially. Clearly, environments cannot support an infinite amount of gang activity. Thus, we assume there is a maximum allowable density of gang activities at each spatial location,

given as a carrying capacity $K_1(s)$. Gang activities will increase in density logistically toward this carrying capacity absent other constraints.

Competitive interactions are present in two forms in equation 1. Within-gang competition is captured by the term $\rho_1(s, t)/K_1(s)$, which limits the activities of gang 1 to densities at or below the carrying capacity discussed earlier. Within-gang competition may be thought of as capturing the conflict between a shared common identity, on the one hand, and the desire to secure money, goods, and attention from the opposite sex, if not simply status (e.g., Anderson, 1999; Valdez, Cepeda, and Kaplan, 2009), on the other. Within-gang competitive interactions over these limited resources reduce the gang's potential to expand activities, because it is harder either to recruit new members or to increase participation of existing members. Note that within-group competitive interactions become more severe as the density of gang 1's activities approach the environmental carrying capacity. Thus, the activity growth rate r_1 declines in proportion to $1 - \rho_1(s, t)/K_1(s)$, reaching zero when the density of activities reaches carrying capacity, and turning negative if activity densities exceed the carrying capacity.

Between-gang competition is captured by the term $\alpha_{21}\rho_2(s, t)/K_1(s)$, which behaves in a manner similar to within-gang competition. Gang 2's activities use up some portion of the carrying capacity available to gang 1, reducing the latter's ability to expand its own activities. The competition coefficient α_{21} captures how big an impact gang 2's activities have on gang 1. Framed in terms of gang violence, for example, $\alpha_{21} = 1$ implies that an increase in attacks by gang 2 dampens gang 1's ability to expand its own activities equivalent to gang 1 having mounted the attacks itself. If $\alpha_{21} = 2$, by contrast, the same increase in attacks by gang 2 is equivalent to gang 1 having added two times the number of attacks. In the latter case, between-gang interactions have twice the competitive impact of within-gang competitive effects. Importantly, the competition coefficient may be thought of as measuring the rivalry strength between gangs.

We also allow for the possibility that the density of gang activities may decay or decline with time, which is captured in the final term $\gamma_1\rho_1(s, t)$. Activity decay may occur because individuals voluntarily or involuntarily leave the gang (see Maxson, 2011) or because external forces such as family, friends, or policing efforts pressure individuals to scale back overt gang-related behavior (Kennedy, Braga, and Piehl, 2001; Thornberry et al., 2003). The rate at which the activities decay is a constant γ_1 proportional to the existing activity density $\rho_1(s, t)$. Thus, the downward pressure on gang activities seems quantitatively higher the closer activities are to nearing carrying capacity.

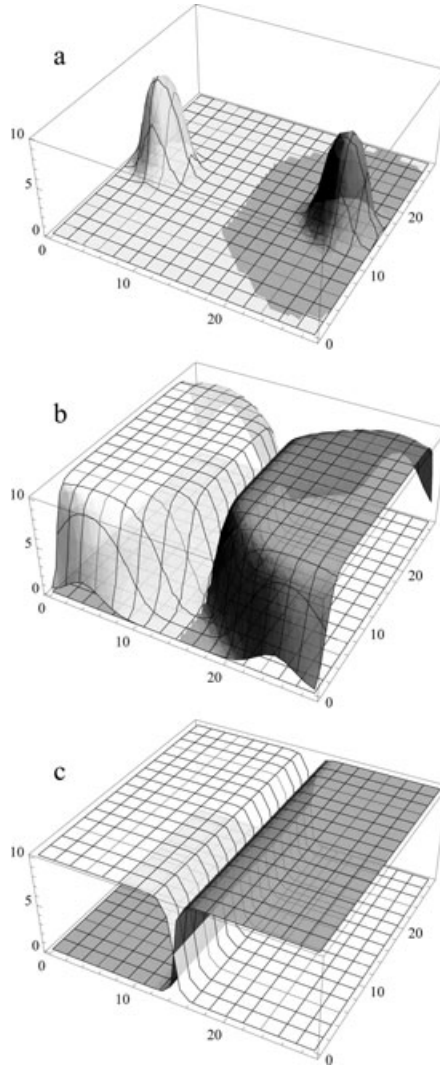
The activities of gang 2 evolve in the same manner as gang 1, and in principle, networks of competing gangs could be described by multiple coupled

PDEs of the form of equation 1 (Smith et al., 2012). We say that equation 1 is *coupled* because the equation for gang 1 contains a term describing the current state of gang 2, and vice versa. Therefore, any change in the density of gang 1 activities impacts the activities of gang 2, and vice versa. In a community of three or more gangs, the terms of the form $\alpha_{kj} \rho_k(s, t) / K_j(s)$ would be needed to describe the impact of each added rival gang k on the dynamics of the focal gang j . Finally, note that each model parameter could theoretically vary through space. For example, we have written explicitly $K_1(s)$ to indicate that the carrying capacity for gang 1 could vary from one location to another based on local environmental conditions. This possibility is investigated by Case et al. (2005) for a traditional ecological problem. Intrinsic growth and decay rates also could vary through space, which we would write as $r_1(s)$ and $\gamma_1(s)$, respectively. We do not investigate these model variants here.

GANG TERRITORIES FORM BY COMPETITION ALONE

Equation 1 has been extensively studied in ecology, and it produces some surprising results that are immediately relevant to understanding the nature of criminal gang territories (see Case et al., 2005; Case and Taper, 2000). Figure 1 shows how gang territories may evolve toward an equilibrium arrangement in space. The exact choice of parameter values for the model is arbitrary. However, it is critical that we assume the gangs are exactly equivalent in their modeled characteristics and have anchor points in equivalent positions within the environment. From small, isolated areas of concentrated activities, each gang expands its activities outward (figure 1a). We do not expect to be able to observe empirically the earliest stages of gang emergence and spread. However, it is assumed that points of origin are approximately coincident with set spaces, which are observable anchor points of activity for the gang. Regardless, we envision the density of gang activities to spread both gradually and locally relative to the rapid rates at which individuals move around their environment. After some time, activity spaces associated with the two gangs meet at the interior of the environment, at which point the gangs begin to compete with one another (figure 1b). The two gangs eventually form relatively compact, symmetrical territories with sharp boundaries and relatively narrow zones of overlap (figure 1c) (Case et al., 2005). This result is surprising because there are no exogenous environmental structures driving the emergence of territories with sharp boundaries, let alone the size and shape of those territories. It is even more surprising because the gangs are exactly equivalent their characteristics.

Figure 1. The Evolution of Gang Territories Starting from Small Initial Activity Densities



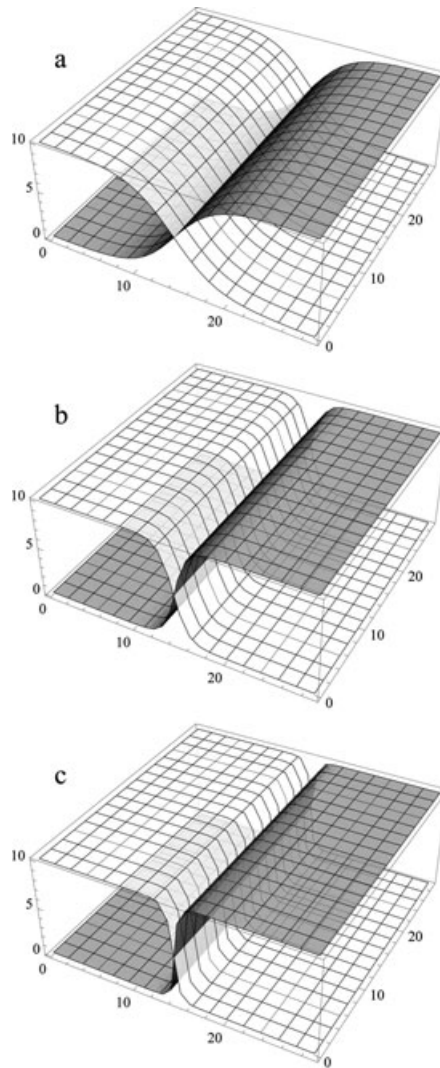
(a) Gangs initiate their activities in two equivalent geographic positions on opposite sides of the environment. Shown is the density of activities for two different gangs after 80 time steps of equation 1. (b) Spatial distribution of activities after 300 time steps. (c) The equilibrium arrangement of gang activities in space at 10,000 time steps shows symmetric territories with a small zone of overlap. The two gangs are equivalent with identical diffusion constants $D_1 = D_2 = .02$, activity growth rates $r_1 = r_2 = .5$, activity carrying capacities $K_1 = K_2 = 10$, intergang competitive effects $\alpha_{21} = \alpha_{12} = 1.5$, and activity decay rates $\gamma_1 = \gamma_2 = 0$.

Specifically, both gangs have identical activity growth rates $r_1 = r_2 = .5$, activity decay rates $\gamma_1 = \gamma_2 = 0$, and activity carrying capacities $K_1 = K_2 = 10$, as well as symmetrical starting locations, equidistant from environmental boundaries, and symmetrical competitive effects $\alpha_{21} = \alpha_{12} = 1.5$. Overall, competition among rivals combined with a tendency for gangs to expand their activities gradually through space is sufficient to drive the emergence of territories.

Equation 1 provides a basis for understanding the equilibrium spatial arrangement of territories under different levels of gang competition, or different rivalry strengths. First, assuming that all model parameters are identical and symmetric for both gangs, stable territorial boundaries form only if $\alpha > 1$; in which case, the activities of a rival gang have a greater impact on a focal gang's ability to grow than the focal gang's own activities. If $\alpha \leq 1$, rival gangs have an impact less than a focal gang's own activities. Under these conditions, gangs may temporarily dominate in a region near the anchor points where they originally appeared. However, the only stable equilibrium arrangement when $\alpha \leq 1$ is for the activities of both gangs to be equally represented in the environment at densities $\rho_1(s, t) = \rho_2(s, t) = K(s)/(1 + \alpha)$. In other words, no discrete territories form when $\alpha \leq 1$. By contrast, when competition increases such that $\alpha > 1$, unique areas of dominance emerge with a transition point placed equidistant between and perpendicular to the anchor points of the two gangs. Figure 2a, for example, shows the case where $\alpha_{21} = \alpha_{12} = 1.01$, meaning that the activities of rival gangs have a competitive effect only slightly greater than the impact of each gang's own activities on itself. Here gang 1 dominates on one side of the environment and gang 2 on the other side and there is a clear point of transition between areas dominated by each. Rival gang activities still occur within each other's territories but only at relatively low densities. In figure 2b, rivalry strengths are slightly higher ($\alpha_{21} = \alpha_{12} = 1.1$), which leads to more complete partitioning of space along a more abrupt territorial boundary. With very high competitive effects ($\alpha_{21} = \alpha_{12} = 3$), activity areas for each gang become almost mutually exclusive (figure 2c).

All of these observations are strict equilibrium results in the mathematical sense. Two gangs that are exactly identical in their basic characteristics; occupy symmetrical locations in an environment; and have reciprocal, between-gang competitive effects stronger than within-gang effects (i.e., $\alpha_{21} = \alpha_{12} > 1$) will form stable territories wherein their activities are numerically dominant. Once formed, such territories will remain stationary for an indefinite period of time, provided there is no fundamental change in the characteristics of either gang. Strict equilibrium does not hold if any of the previous assumptions are violated. Rather, one gang ultimately drives its rival out of the environment, a classic case of competitive exclusion (Armstrong and McGehee, 1980). For example, if either gang starts with

Figure 2. Equilibrium Spatial Distribution of Criminal Gang Activity as a Function of Rivalry Strength



(a) Rivalry strength is $\alpha = 1.01$, meaning that a rival has a very small increased competitive effect relative to one's own gang. (b) Rivalry strength is $\alpha = 1.1$, giving a slightly higher competitive effect. (c) Rivalry strength is $\alpha = 3$, meaning that rivals have an impact three times greater than within-gang effects. The two gangs are equivalent in other attributes including activity growth rates $r_1 = r_2 = .1$, activity carrying capacities $K_1 = K_2 = 10$, and decay rates $\gamma_1 = \gamma_2 = 0$, as well as symmetrical initial starting locations. All simulations are run sufficiently long to produce distributions that do not change in time.

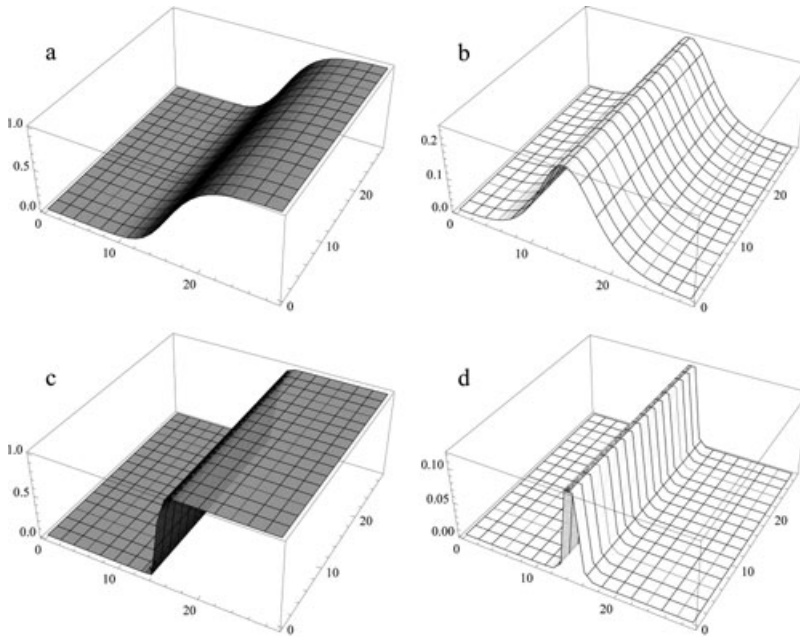
a higher initial activity density, has a geographically advantageous anchor point, or has greater fundamental growth rate, then competitive exclusion will occur with certainty given enough time. Similarly, if there are rivalry imbalances (e.g., $\alpha_{21} > \alpha_{12}$), then the competitively superior gang will ultimately replace the competitively inferior gang given enough time.

At least two factors lead unstable, asymmetrical gang rivalries to behave much like stable, symmetrical ones, even though strict equilibrium does not hold. First, territories formed by gangs under asymmetric conditions may nonetheless be quasi-stationary for *very long* periods of time. Indeed, the general dynamic for both symmetrical and asymmetrical models is for territorial boundaries to form very quickly and then, once formed, for the boundary to change extremely slowly until competitive exclusion occurs. Typically, competitive exclusion occurs at a time several orders of magnitude *after* the formation of a territorial boundary. Rapidly forming boundaries are likely to be immediately salient to the behavior of gangs, even if those boundaries are ultimately expected to collapse under competitive pressure. The implication is that we are still likely to observe what seem to be stationary territorial boundaries even where gangs are not equivalent in their characteristics. Second, real-world environments are heterogeneous, which may lead to spatial “pinning” of territorial boundaries (e.g., Nattermann, Shafir, and Vilfan, 1990). The coarse structure of the built environment may slow down or limit the diffusion of gang activities through space stabilizing boundaries that might otherwise collapse under competitive pressure. Empirically, gang asymmetries may produce curved territorial boundaries and unequal territory sizes, compared with the straight boundaries and equal territory sizes under stable, symmetrical dynamics. Importantly, the closer gangs are to meeting symmetry requirements for stability, the more their territories’ boundaries should resemble the strict equilibrium case. We do not formally explore asymmetrical model variants here.

DISTRIBUTION OF WITHIN- AND BETWEEN-GANG VIOLENCE

Competitive effects operating among spatially distributed rival gangs are alone sufficient to produce sharp territorial boundaries between gangs, without any other significant difference between them. By recognizing this, we can use equation 1 to produce expectations about the relative volume and spatial distribution of within- and between-gang competition. At equilibrium, the amount of within-gang competition experienced by gang 1 at location s is $r_1 \rho_1(s) [\rho_1(s) / K_1(s)]$. The amount of local between-gang competition at equilibrium experienced by gang 1 at location s is likewise $r_1 \rho_1(s) [\alpha_{21} \rho_2(s) / K_1(s)]$. In general, within- and between-gang competition

Figure 3. Spatial Distribution of Violence Directed Against Gang 1



(a) Within-gang attacks where the victim and perpetrator of a violent attack self-identify with the same gang. Competitive effects are $\alpha_{21} = \alpha_{12} = 1.01$. (b) Between-gang attacks where the victim is from gang 1, but the perpetrator is from rival gang 2. Competitive effects are $\alpha_{21} = \alpha_{12} = 1.01$. (c) The distribution of between-gang attacks becomes increasingly concentrated along a sharp boundary between gangs as gangs increase their rivalry symmetrically. Competitive effects are $\alpha_{21} = \alpha_{12} = 1.5$. (d) The distribution of between-gang attacks becomes increasingly concentrated along a sharp boundary between gangs as gangs increase their rivalry symmetrically. Competitive effects are $\alpha_{21} = \alpha_{12} = 1.5$. *NOTE:* In all cases, $r_1 = r_2 = .1$, $K_1 = K_2 = 10$, and $\gamma_1 = \gamma_2 = 0$.

could be realized through any number of gang-related activities including tagging (Block and Block, 1993; Klein, 1995), aggressive displays (Decker and Van Winkle, 1996; Vigil, 1988), and drug dealing (Cohen et al., 1998; Hagedorn, 1994). Here we make the reasonable assumption that violence, although certainly underreported, is proportional to competitive effects. We may then map out the expected spatial distribution of violent crimes both within and between rival gangs (figure 3). The model predicts that within-gang violence will be highest in the gang's own territory (figure 3a). Attacks between rivals will be distributed along the boundary between gangs (figure 3b), which will be equidistant between and perpendicular to the gang spaces or anchor points. Furthermore, it is visually apparent

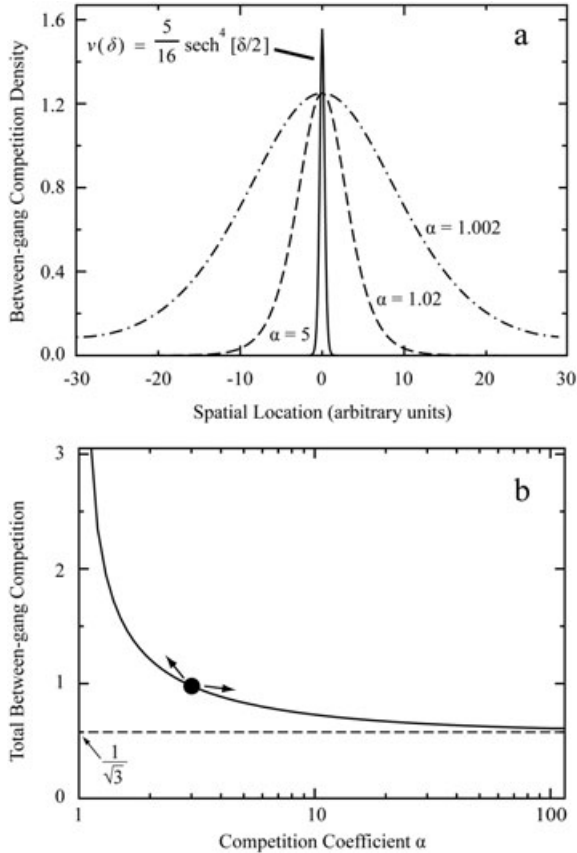
that the shape of the distribution of between-gang violence around the theoretical boundary is not Gaussian normal. It is difficult to specify the exact form of this distribution except in a few special cases. In the symmetric one-dimensional case, where two gangs compete with one another along a straight line and the gangs have symmetric rivalry strengths $\alpha_{21} = \alpha_{12} = 5$, one can show that the density of between-gang violence is a hyperbolic secant distribution of the form $v(\delta) \propto \text{sech}^4[\delta/2]$, where δ is the distance from the territory boundary (figure 4a). Hyperbolic secant distributions are more peaked and have heavier tails than Gaussian normal distributions. In other words, between-gang violence is predicted to be more tightly clustered at the boundary between gangs; yet also, it will occur at greater distances from the boundary than expected with a Gaussian distribution of competition. We will test this hypothesis in the next section.

Based on our previous discussion, we also should expect that the total amount of between-gang violence will change as competitive interactions change. The direction of change is perhaps counterintuitive, however. For example, figure 3c shows that if a rivalry between two gangs escalates symmetrically, within-gang violence increases over the area held by each gang. The spatial distribution of between-gang violence, however, compresses into an increasingly sharp wedge between the gangs (figure 3d and figure 4a). In the one-dimensional case, one can show that as α increases, the total amount of between-gang violence asymptotically decreases toward a constant value $1/\sqrt{3}$ (figure 4b). As a practical matter, this constant is difficult to translate into an explicit prediction about the total amount of violence to expect under extreme levels of competition. It does imply, however, that space is never completely partitioned by rival gangs. Rather, there will always be some amount of overlap in gang territories. The previous observations may have important implications for policing gang rivalries that we revisit in the discussion.

TESTABLE HYPOTHESES

The spatial Lotka–Volterra competition model provides potential insights into the role that competition both within and between gangs may play in driving gang territory formation. The model makes several explicit predictions. The model predicts that stable territories will form between gangs when they are symmetrical in certain key characteristics. Territorial boundaries also should take the form of a linear feature equidistant between and perpendicular to gang set spaces or activity anchor points. The model also suggests that within-gang violence should be restricted primarily to locations within a gang's own territory. We do not test these predictions directly. Rather, we concentrate on two predictions related to the distribution of between-gang competitive interactions:

Figure 4. The Spatial Distribution and Intensity of Between-Gang Violence in Relation to Competitive Strengths



(a) Symmetric Lotka–Volterra competition model where gangs compete along a line. The distribution of between-gang competition $v(\delta)$ can be solved explicitly for $\alpha = 5$ and takes the form indicated. For other values of α , the distribution cannot be solved explicitly but remains significantly different from a Gaussian normal distribution. (b) The total amount of between-gang violence decreases asymptotically to a constant as the competition coefficient α increases. A point of reference is provided for considering how changes in the competition coefficient impact the total amount of between-gang violence.

Hypothesis 1 (H1): Between-gang violence will cluster along the theoretical boundary between gangs.

Hypothesis 2 (H2): The shape of the distribution of between-gang violence around the theoretical boundary will be non-Gaussian, with a prominent peak and fat tails.

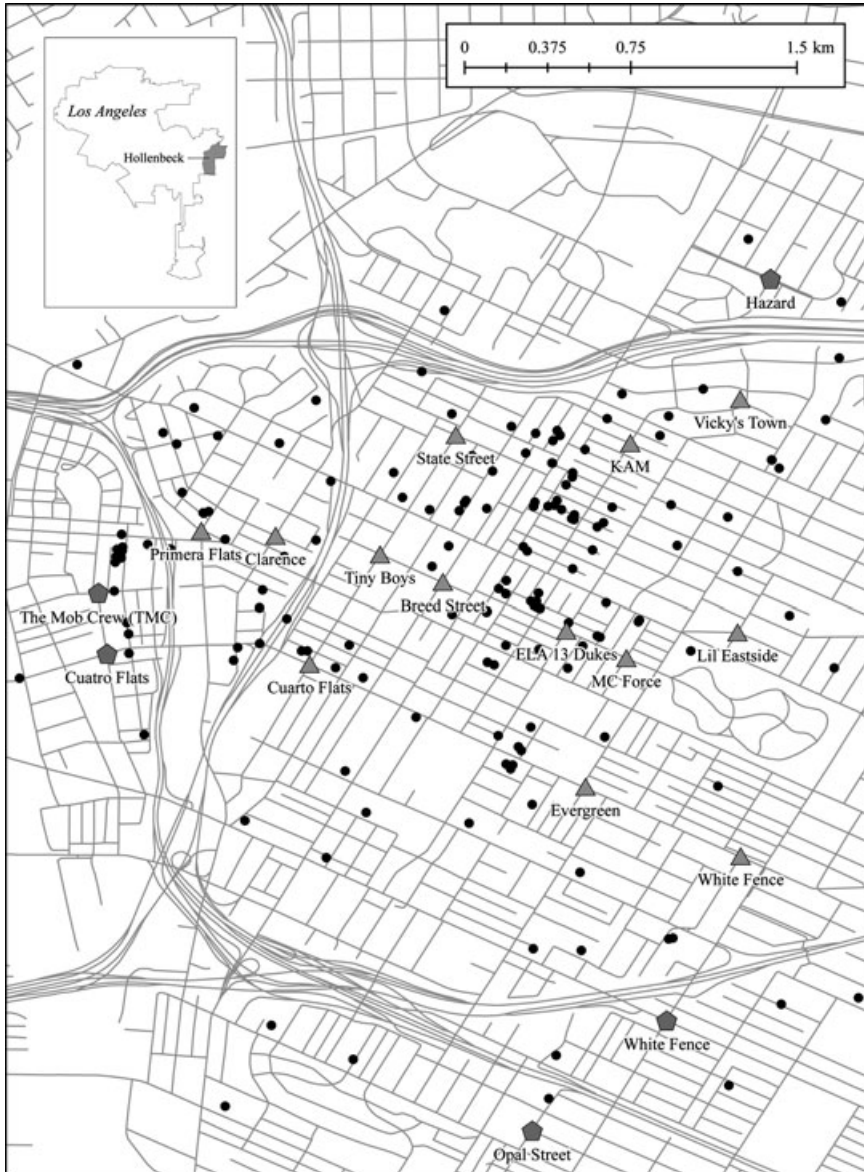
The prediction that between-gang violence will cluster along the theoretical boundary between gangs (H1) may be tested by using data on the spatial locations of violence where the suspect and victim gang identities are known. As discussed, the theoretical boundary for any pair of gangs is a linear feature equidistant between and perpendicular to gang set spaces or activity anchor points. Distributions of between-gang violent events that *do not* center on the theoretical boundary offer sufficient evidence to reject the model in its current form. Hypothesis 2 (H2), which concerns the shape of the distribution of between-gang violence around the theoretical boundary, may provide a more refined test of the model. To wit, if the distribution of between-gang violence *is not* strongly peaked with corresponding fat tails, but assumes a Gaussian normal, or some other distributional form, then the model may be rejected in its present form.

GANG VIOLENCE IN HOLLENBECK, LOS ANGELES

Hollenbeck is a 15.2-square-mile (39.4-km²) policing division of the Los Angeles Police Department (LAPD), located on the eastern edge of the city of Los Angeles (figure 5). Hollenbeck has approximately 220,000 residents, of which the majority are Hispanic (68.9 percent), with most tracing ancestry to Mexico. Hollenbeck is bounded in the north by the Los Angeles River, the west by Interstate 5, and the south by the 60 Freeway. It is bisected by Interstate 10, with the Lincoln Heights and El Sereno neighborhoods to the north, and the Boyle Heights neighborhood to the south. These boundaries are largely impermeable to gang activity such that gangs within Hollenbeck rarely attack gangs outside of Hollenbeck, and those gangs located south of Interstate 10, in the Boyle Heights neighborhood, have limited interactions with gangs to the north. Our analysis will concentrate on violent crimes among the criminal street gangs located south of Interstate 10 in the Boyle Heights neighborhood (see the subsequent discussion).

Tita et al. (2003) identified 29 active criminal street gangs in Hollenbeck as a whole. These 29 gangs formed at least 66 unique rivalries. Gangs and their rivalries were identified by LAPD gang intelligence detectives and cross-checked with reported crime incidents involving one or more known gangs. A rival is defined as any target gang identified by a focal gang as an enemy. Gangs generally do not recognize allies, but they are ambivalent toward nonrivals. In Hollenbeck, for example, the gang TMC (“The Mob Crew”) identifies both Primera Flats and Cuatro Flats as rivals, but it is neutral toward gangs such as Breed Street and Clarence. Most violent exchanges between gangs are between known rivals (see subsequent discussion). Crimes may occasionally occur between gangs not recognized as sharing a rivalry, but these are rare by comparison. Each gang also has

**Figure 5. Locations of Gang Violent Crimes 1999–2002
Among 13 of the 29 Active Gangs in the Southern
Half of the Hollenbeck Policing Division of Los
Angeles (Inset)**



NOTE: Gang set space locations are shown for gangs within (triangles) and immediately outside (pentagons) the sample area.

an anchor point for its activities, known as its “set space” (Tita, Cohen, and Engberg, 2005), and claims a surrounding territory. Most gang-focused social activity is conducted within the territory boundaries, although it is not the case that individual or small groups of gang members never stray farther afield during the course of gang-related or normal, daily activities.

In most of the reported violent incidents reported to the police, it is not possible to know what the proximate social or economic goal of the violence may have been. In practice, therefore, violent crimes are attributed to gangs only when at least one of the parties involved is a known or suspected gang member. In Hollenbeck between November 14, 1999 and September 28, 2002 (1,049 days), there were 1,208 violent crimes recorded by the LAPD that were attributed to criminal street gangs in the area. Of these, 1,132 crimes explicitly identify the gang affiliation of the suspect, victim, or both. The discrepancy reflects violent crimes such as “shots fired,” where the suspect and intended victim may not be clear but the status as a gang crime is not questioned based on location and crime characteristics. Violent crimes include assault with a deadly weapon, attempted homicide, and homicide. For each violent crime, Tita, Cohen, and Engberg (2005) collected information on the street address where the crime occurred as well as the date and time of the event, allowing examination of the spatio-temporal dynamics of gang violence. They also used information present already in the data, as well as consultation with LAPD gang detectives, to code the suspect and victim gangs in each event. Set spaces or anchor points for each gang were recorded based on reporting by LAPD gang detectives (Tita, Cohen, and Engberg, 2005). Approximate territory boundaries also are known from the same source. We make use of reported set space locations in what follows but not reported territory characteristics.

Our analysis focuses on violent crime attributed to 13 of Hollenbeck’s 29 active criminal street gangs (table 1 and figure 5). The 13 gangs occupy territories in the Boyle Heights neighborhood, bounded by Interstate 5 in the west, Interstate 10 in the north, Los Angeles County in the east, and the 60 Freeway in the south. These features serve as boundaries to interactions with gangs outside of the study area. Rivalries identified by LAPD gang intelligence detectives show that most connections are internal to Boyle Heights. Most violent exchanges also are internal. Table 1 shows the number of violent crimes attributed to each focal gang separated according to whether they are the suspect or the victim in a crime. A total of 563 violent events are attributed to at least 1 of the 13 study gangs in their roles as suspects and victims. A subset of the total has both the suspect and the victim gang known, allowing us to examine spatial patterning of dyadic interaction between those known gangs. There are a total of 179 events where both the focal suspect gang is known and the (nonfocal) victim gang is known. There are 176 events where the both the focal victim

Table 1. Number of Violent Crimes 1999–2002 Attributed to Each of 13 Focal Gangs in Hollenbeck, Los Angeles, Separated According to Whether the Focal Gang Is the Suspect or the Victim

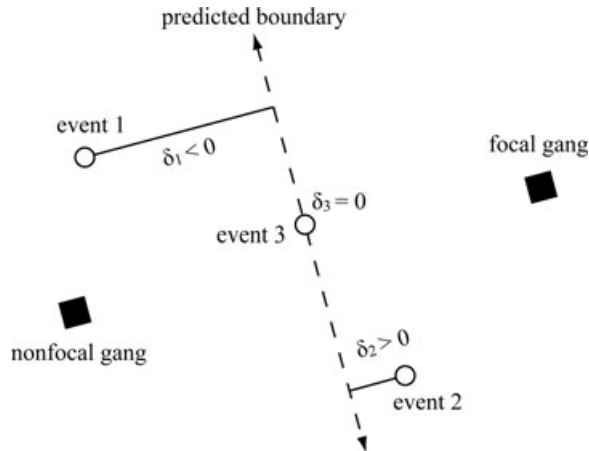
Focal Gang	Victim	Suspect	Total
KAM	28	113	141
State Street	19	73	92
White Fence	26	64	90
Cuatro Flats	18	53	71
MC Force	22	36	58
Primera Flats	16	33	49
ELA-13 Tiny Dukes	17	30	47
Breed Street	3	33	36
Tiny Boys	13	20	33
Clarence	13	15	28
Evergreen	7	14	21
Vicky's Town	7	14	21
Lil Eastside	3	5	8
Unkown Affiliation ^a	324	27	351
Outside Affiliation ^b	47	33	80
TOTAL	563	563	1126

^aEvents where gang affiliation of the victim, intended victim, or suspect is not known.

^bEvents involving gangs where the affiliation is known but the gang is located outside of the designated study area.

gang is known and the (nonfocal) suspect gang is known. KAM (“Krazy Ass Mexicans”) is the most active street gang, with known involvement in 141 violent crimes over 1,049 days: 113 events as the suspect and 28 events as the victim. KAM is thus party to one event every week on average. Four other gangs were involved in more than 50 events each (State Street, White Fence, Cuatro Flats, and MC Force). In each case, the number of events in which they are a suspect exceeds the number of events where they are the victim. Seven gangs were involved in between 20 and 49 violent crimes over the same 1,049 days. Lil Eastside is identified in only eight crimes over the sample period. Overall, there are 324 events where the suspect gang is known but specific affiliation of the victim is not known. There are 27 events where the victim gang is known but the suspect gang is not. A total of 129 events occurred between 1 of the 13 focal gangs and rivals based outside of the study area, either in other areas of Hollenbeck (e.g., Clover or Hazard), in other parts of the city of Los Angeles (e.g., Lil Valley), or in Los Angeles County (e.g., Maywood Locos). We include in the subsequent analyses interactions between any of the 13 focal gangs inside the study area and known gangs outside of the study area. We do not consider interactions among dyads where both gangs are based outside the study area. For example, we track the characteristics of events occurring

Figure 6. Method for Calculating the Location of Violent Crimes in Relation to the Boundary Between Gang Territories Predicted by Theory



NOTES: The boundary is a linear feature equidistant and orthogonal to their respective set spaces. The distance of a crime from the boundary is calculated perpendicular to the boundary. Values of $\delta_n > 0$ are nominally within the focal gang's territory, $\delta_n < 0$ are in the rival's territory, and $\delta_n = 0$ are exactly on the boundary.

between KAM (inside) and Hazard (outside) but not between Hazard (outside) and El Sureno (outside). Only a handful of events were recorded as occurring within individual gangs (e.g., KAM is both suspect and victim). These events were excluded from consideration.

DISTRIBUTION OF GANG CRIME

We map the location of violent crimes in relation to the theoretical territorial boundaries between rival gangs. The spatial Lotka–Volterra competition models predicts that the territorial boundary between two gangs, who are symmetrical in their characteristics, should be a linear feature equidistant and perpendicular to the set spaces of the gangs (figure 6). We treat this theoretical territorial boundary as if it were a total least-squares regression line (Golub and Van Loan, 1980), and we calculate the perpendicular distances between crime locations and the boundary as unstandardized residuals. Positive values for this quantity are deemed to occur within the territory of a focal gang. Negative values identify crimes occurring within the rival gang territory. Values of zero fall exactly along the predicted territorial boundary. Note that the Lotka–Volterra model

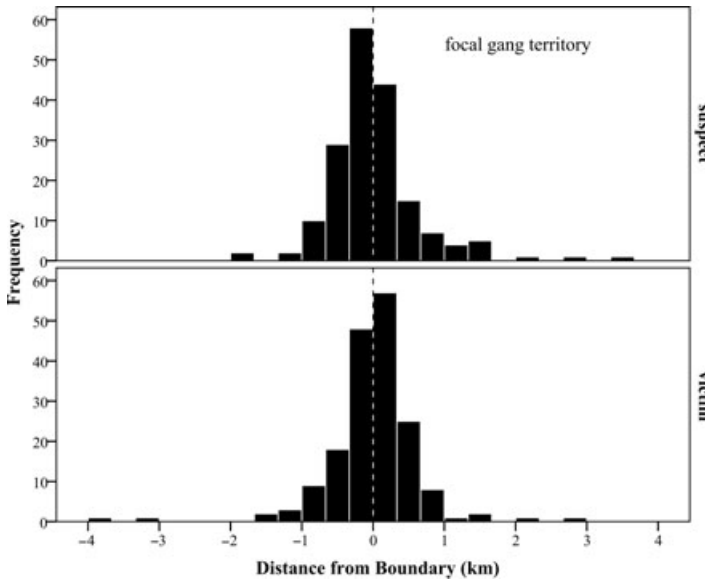
used here evaluates crimes only in relation to dyadic pairs. Thus, the boundary is infinitely long in theory, bisecting the world into a territory occupied by a focal gang and its rival in an event. Accordingly, violent exchanges between two gangs are treated the same whether they are near or far from the central axis between gang set spaces. The only relevant measure here is how far the event falls from the predicted boundary. This prediction of the model may run counter to common sense, which sees gang territorial boundaries as truncated by the built environment or the positioning of rivals on many sides. In a multigang setting, the dyadic Lotka–Volterra model would seem to allow violent exchanges to occur within third-party territories. It is an open question exactly how third-party territories may impact the spatial distribution of dyadic violent exchanges. However, we suspect that the presence of rivals on many sides may constrain events between any two gangs to occur more frequently (but not exclusively) along short segments of the theoretical boundary that are unique to the feuding pair, if such segments exist. The short boundaries produced by the Lotka–Volterra competition equations, in a multigang setting, may align with the edges of the Thiessen polygons constructed around set spaces (see Taniguchi, Ratcliffe, and Taylor, 2011).

We concentrate on dyadic interactions and compute the measured distance from the theoretical boundary separately for instances where a focal gang is the suspect and where it is the victim in a crime. Counting suspects and victims separately allows us to investigate whether competitive interactions differ depending on a gang's role in a violent crime. If the distributions are similarly shaped when gangs are suspects and victims, then this may indirectly support the conclusion that rivalries are approximately symmetrical, as required for stable territory formation.

RESULTS

Violent crime among the 13 focal gangs in Hollenbeck clusters along the theoretical boundary between gangs predicted by the Lotka–Volterra competition model. Figure 7 plots the frequency distribution of the perpendicular distance from the predicted boundary for each event involving a known pair of gangs (see figure 6). The median distance from the boundary is not significantly different from zero regardless of whether the focal gang is a suspect (median $\delta = -.089$ km, Wilcoxon $W = -1.363$, $p = .173$) or a victim (median $\delta = .040$ km, Wilcoxon $W = .492$, $p = .623$). Violent crime frequencies are strongly peaked around the boundary and have “fat tails” (suspect Kurtosis = 6.132; victim Kurtosis = 11.387). Not surprisingly, both suspect and victim distributions are significantly different from normal (suspect: Kolmogorov–Smirnov $D = 1.687$, $p < .007$; victim: Kolmogorov–Smirnov $D = 1.617$, $p < .011$). The distributions are not statistically identical

Figure 7. Crime Locations Cluster Around the Predicted Boundary Between Gang Territories



NOTE: Shown are the distances δ_n from the theoretically predicted boundary separately for focal gangs when they are the suspect ($n = 179$) and when they are the victim ($n = 177$) in a crime.

(Kolmogorov–Smirnov $D = 1.322$, $p < .058$) because focal gangs interact with different sets of outside gangs when they are suspects and when they are victims.

The observed spatial distribution of between-gang violence meets the two primary expectations of the spatial Lotka–Volterra competition model, namely, the clustering of events along the boundary predicted by theory (H1) and the peaked shape of the distribution (H2). We now seek to estimate competition coefficients α for focal gangs by using the observed distributions shown in figure 7. Ideally, to estimate α , one would conduct parameter fitting of an explicit functional form for the distribution of between-gang violence $v(\delta)$. However, as discussed, equation 1 can be explicitly solved for between-gang violence only under certain circumstances. We therefore develop a custom numerical procedure analogous to maximum likelihood estimation to search different parameterizations of equation 1 exhaustively. Specifically, we use a mathematical technique (nondimensionalizing) to simplify the Lotka–Volterra equation, reducing it from a difficult problem with four parameters to one with only two, the competition coefficient α and a system length scale L . We then randomly choose values for these two

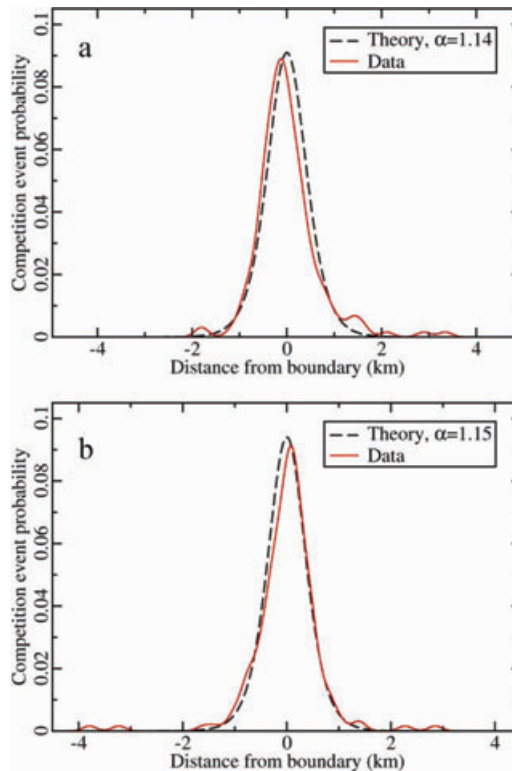
parameters and generate candidate curves $v(\delta)$ for the theoretical distribution of between-gang violence. Because the model is deterministic, we only need to evolve the system once for each corresponding set of parameters. Each theoretical distribution is then compared for statistical goodness of fit with the observed empirical distribution (see subsequent discussion). The best fitting model is retained, whereas poorer fitting models are discarded. We use the distribution-independent, Kolmogorov–Smirnov (KS) test to evaluate model fit, favoring the theoretical model that yields the lowest D -statistic while being statistically equivalent to the observed data (high p value). We then rescale the results for presentation (figure 8).

For focal gangs as suspects, we estimate $\alpha = 1.14$ (Kolmogorov–Smirnov $D = .0883457$, $p = .106$). For focal gangs as victims, we estimate $\alpha = 1.15$ (Kolmogorov–Smirnov $D = .0460124$, $p = .797$). The fact that suspect and victim values are very similar suggests that competition is in fact symmetrical among gang pairs (i.e., $\alpha_{ij} = \alpha_{ji} \sim 1.15$). This symmetry, combined with the fact that $\alpha > 1$, suggests that Hollenbeck gangs should naturally form stable territories through competition alone. Furthermore, between-gang competitive effects in Hollenbeck seem to be only slightly greater than within-gang competitive effects. For example, if gang 2 increases its activity by 10 percent in a given area, then $\alpha = 1.15$ implies an impact on gang 1 equivalent to gang 1 increasing its own activity by 11.5 percent. Such differences in activity densities might be barely noticeable in the field. Contrary to popular perception, measured between-gang competition seems to be relatively low.

DISCUSSION

Violent crimes occur among rival gangs whose territories are distributed across space. Indeed, there seems to be a direct connection between the locations of gang crimes and the placement of territorial boundaries. By using a formal mathematical model—spatial Lotka–Volterra competition equations—we derived the prediction that the territorial boundary between any two rival gangs should be a linear feature equidistant between and perpendicular to the set spaces or anchor points of the two gangs. The theory predicts that the distribution of between-gang violence should not only cluster around the theoretical boundary, but also it should assume a unique shape strongly peaked at the center and with “fat tails.” Empirical evidence on the spatial distribution of violent crimes occurring among 13 rival gangs in the Hollenbeck Policing Division of Los Angeles is consistent with both predictions. Specifically, observed violent crimes center on the predicted boundary from the viewpoint of both suspect and victim gangs. The distribution of observed between-gang crimes also is non-normal in precisely the way predicted by theory. Natural urban features do not seem

Figure 8. Numerical Comparison of the Observed Distribution of Violent Crime Distances from the Territory Boundary with Theoretical Predictions from the Spatial Lotka–Volterra Competition Model



NOTES: Comparisons were implemented via numerical simulation with candidate solutions chosen by finding theoretical distributions that are statistically equivalent to the observed (see text for details). Estimated competition coefficients are very similar for focal gangs both as (a) suspects $\alpha = 1.14$ and as (b) victims $\alpha = 1.15$.

to be responsible for this clustering, although features such as major free-ways do seem to constrain which gangs are likely to interact (see Smith et al., 2012). Rather, the clustering of gang crime along predicted boundaries is consistent with the hypothesis that competition plays a primary role in determining the organization of gang territories (Case et al., 2005; Case and Taper, 2000; but see Gaston, 2009). The territorial limits for individual gangs, therefore, are not unlike the territorial limits observed for many other nonhuman animals competing within spatial habitats (Jankowski,

Robinson, and Levey, 2010; Moorcroft, Lewis, and Crabtree, 2006; Smith et al., 2012).

The correspondence between the observed patterns of between-gang violence and the spatial Lotka–Volterra competition model also points to interesting and possibly surprising conclusions about gang interactions and gang territoriality. First, the formation of gang territories via competition implies that the strength of between-gang competitive interactions is greater than within-gang competitive interactions (i.e., $\alpha > 1$). If opportunity were all that mattered, then one would expect within-gang competitive interactions to outweigh between-gang competitive interactions. Second, gang territories can be strictly stable only if competing gangs are symmetrical in certain characteristics. Symmetry is required in gang activity growth and decay rates, activity carrying capacities, and particularly, competitive abilities. Without this symmetry, gangs with a competitive advantage would tend to replace those at a disadvantage, although such replacements could take a very long time. Importantly, the model is silent about the need for equivalence (or lack thereof) in other gang traits. The evidence suggests the conditions for stability may be nearly met within the community of Hollenbeck gangs. By using a numerical method to fit the theoretical model to observed between-gang crimes, we estimated competition coefficients of $\alpha = 1.14$ and $\alpha = 1.15$ for focal gangs as suspects and victims, respectively. Although there is good reason to be cautious in interpreting overall community dynamics from a single index (Abrams, 2001), the results do suggest that Hollenbeck gangs occupy a regime (i.e., $\alpha > 1$) where competition is sufficient to drive boundary formation. Moreover, the similarity of estimated competition coefficients when gangs are victims and when they are suspects suggests that rivalries are approximately symmetrical in at least competitive ability (i.e., $\alpha_{ij} = \alpha_{ji} \sim 1.15$). Therefore, we expect that gang territorial boundaries may be stable, or nearly so, through competitive interactions alone. Further empirical efforts to characterize symmetry (or the lack thereof) of gang activity growth rates, activity decay rates, and the urban locations of gang set spaces may help clarify the accuracy of this observation.

It is equally interesting that the estimated values of α are so low. It is hard to characterize them as reflecting “extreme” competition. Interpreted in terms of the activity per gang member, a value of $\alpha \sim 1.15$ implies that the activity generated by seven members to a rival gang has a competitive effect equivalent to the activity of approximately eight members in the focal gang. This difference in within- and between-gang effects hardly seems large, although the exact nature of within-gang competition is difficult to assess. Interaction effects, including competition, are typically clustered around neutral values within ecological communities, with a very small number of species exhibiting strong effects (Wootton and Emmerson, 2005). Such also

may be the case with criminal street gangs, where one or two gangs may have a large impact on rivals, but the majority have only small, marginal effects on one another (Decker and Curry, 2002; Papachristos, 2009).

Despite these findings, we emphasize that the Lotka–Volterra competition equations do not rule out the possibility that other processes might be important in some alternative explanation of gang territory formation. Nor do we claim that Lotka–Volterra explains all aspects of gang territorial behavior. The models suggest that fixed geographic barriers within the environment such as freeways or other urban features are not necessary for the production of distinct gang territories, nor are they needed to explain the observed distribution of gang violence. However, this conclusion is not the same thing as claiming that geographic barriers have no consequences for gang behavior. We suspect that the spatial scale at which geographic (or demographic) barriers operate is coarser than that describing competition effects. For example, in Hollenbeck, it is clear that the gangs within the Boyle Heights neighborhood interact much less frequently with the gangs outside this bounded area (Radil, Flint, and Tita, 2010). The freeways and portion of the Los Angeles River that form the boundaries of Boyle Heights are clearly significant in limiting interactions over wider geographic areas (see Smith et al., 2012). Ultimately, a comparison of the theoretical predictions from the Lotka–Volterra competition equations and direct evidence of territory boundaries is needed.

The Lotka–Volterra competition equations do not purport to explain all aspects of gang territorial behavior. Indeed, we expect both within- and between-gang competitive interactions to vary at much finer spatial scales than considered by Lotka–Volterra. Territorial defense models, for example, may better capture some finer scale dynamics, particularly the tendency for individuals to react differently to immediate neighbors than to strangers (see also Moorcroft, Lewis, and Crabtree, 2006; Temeles, 1994; Ydenberg, Giraldeau, and Falls, 1988). In some animal species, individuals are observed to act less aggressively toward neighbors than strangers, somewhat contrary to the situation with gangs. Neighbors may be spared greater aggression in these animal cases because the rival recognizes them as adjacent territory holders who are unlikely to be seeking to usurp territorial rights. Neighbors thus share an incentive to minimize the energy they expend in fighting one another, saving their effort for strangers who are more likely to be in search of a territory to occupy. Neighbors also may know more about one another's competitive abilities—who is likely to prevail in a contest—and therefore, the competitor with the weaker hand is less likely to initiate conflict. With criminal street gangs, however, it is far more common for neighbors to be engaged in conflict than non-neighbors.

Recognize also that finer scale territorial defense models assume the formation and stability of territories as *a priori* conditions for competition.

The intention of territorial defense models is to understand the distribution of aggression given territoriality. What we have observed here clearly bears on this question. However, the purpose of this article has been to take a step back and investigate how competition might drive territory formation in the first place. In essence, we treat territoriality as a by-product of aggression rather than the other way around. The fact that the observed spatial distribution of between-gang violence in Hollenbeck is consistent with the latter model suggests that it may be broadly correct.

In conclusion, we note that modeling gang violence in terms of ecological processes may raise interesting implications for policing. First, the formation of stable gang territories requires only that between-gang competitive effects be marginally stronger than within-gang effects. That gangs occupy stable territories does not necessarily imply that rival gangs exist in a constant, extreme state of war. Rather, information about the extent or severity of competitive interactions is indicated by the degree of overlap in gang activities. Greater overlap in the activity spaces of rival gangs indicates lower levels of competition, whereas sharper boundaries tend to imply more intense competition. A second, related observation concerns the common notion that reducing the intensity of gang rivalries offers the best approach to reducing gang violence. The spatial Lotka–Volterra model suggests that the opposite may be the case. By assuming $\alpha > 1$, the necessary condition for territories to form, any reduction in rivalry strength should lead to greater encroachment of gangs into their rival's territories (see figure 2). The one-on-one impact of single interactions may be reduced by such an action, but between-gang violent crime may increase overall simply because of the greater volume of interactions brought on by greater territorial overlap. Indeed, figure 4b suggests that between-gang violence should increase sharply as the intensity of competition decreases. Conversely, increased competition between gangs should reduce between-gang violence, but it will never cause it to disappear completely. In principle, it is possible to do comparative testing of this final prediction given information of gang intervention practices and their variation across populations.

CONCLUSIONS

Competition between rival gangs seems to follow closely patterns of territorial aggression. We use spatially explicit Lotka–Volterra competition models to evaluate the role of between-gang competition in the formation of stable gang territories. The model makes explicit predictions about the spatial distribution of between-gang violent crime, which we evaluate by using data from the Hollenbeck area of Los Angeles. Observed competitive interactions between gangs are concentrated around territorial boundaries and take on non-normal distribution shape, where both observations are

consistent with the expectations of the Lotka–Volterra model. Estimates of the intensity of competition between gangs suggest that it is only marginally greater than that within gangs. The results suggest that the Lotka–Volterra competition model has merit, but they do not rule out the possibility that other processes might be part of an alternative plausible explanation of gang territory formation.

REFERENCES

- Abrams, Peter A. 2001. Describing and quantifying interspecific interactions: A commentary on recent approaches. *Oikos* 94:209–18.
- Ahrentzen, Sherry, ed. 1990. *Rejuvenating a Field That is Either “Coming of Age” or “Aging in Place”: Feminist Research Contributions to Environmental Design Research, Coming of Age: Proceedings of the 21st Annual Conference of the Environmental Design Research Association*. Oklahoma City, OK: Environmental Design Research Association.
- Anderson, Elijah. 1999. *Code of the Street: Decency, Violence, and the Moral Life of the Inner City*. New York: Norton.
- Armstrong, Robert A., and Richard McGehee. 1980. Competitive exclusion. *The American Naturalist* 115:151–70.
- Begon, Michael, Colin R. Townsend, and John L. Harper. 2006. *Ecology: From individuals to ecosystems*. Oxford, U.K.: Blackwell.
- Bjerregaard, Beth. 2002. Self-definitions of gang membership and involvement in delinquent activities. *Youth & Society* 34:31–54.
- Block, Carolyn R., and Richard Block. 1993. *Street Gang Crime in Chicago*. Washington, DC: National Institute of Justice.
- Brenig, Leon. 1988. Complete factorisation and analytic solutions of generalized Lotka–Volterra equations. *Physics Letters A* 133:378–82.
- Campbell, Anne. 1984. *The Girls in the Gang*. Oxford, U.K.: Basil Blackwell.
- Cartwright, Desmond S., and Kenneth I. Howard. 1966. Multivariate analysis of gang delinquency: I. Ecologic influences. *Multivariate Behavioral Research* 1:321–71.
- Case, Ted J., Robert D. Holt, Mark A. McPeck, and Timothy H. Keitt. 2005. The community context of species’ borders: Ecological and evolutionary perspectives. *Oikos* 108:28–46.

- Case, Ted J., and Mark L. Taper. 2000. Interspecific competition, environmental gradients, gene flow, and the coevolution of species' borders. *American Naturalist* 155:583–605.
- Cohen, Jacqueline, Daniel Cork, John Engberg, and George Tita. 1998. The role of drug markets and gangs in local homicide rates. *Homicide Studies* 2:241–62.
- Cosner, Chris, and Alan C. Lazer. 1984. Stable coexistence states in the Volterra-Lotka competition model with diffusion. *SIAM Journal on Applied Mathematics* 44:1112–32.
- Decker, Scott H., and G. David Curry. 2002. Gangs, gang homicides, and gang loyalty: Organized crimes or disorganized criminals. *Journal of Criminal Justice* 30:343–52.
- Decker, Scott H., and Barrik Van Winkle. 1996. *Life in the Gang: Family, Friends and Violence*. New York: Cambridge University Press.
- Donnan, Hastings, and Thomas M. Wilson. 1999. *Borders: Frontiers of Identity, Nation and State*. Oxford, U.K.: Berg.
- Donohue, John J., III, and Steven D. Levitt. 1998. Guns, violence, and the efficiency of illegal markets. *The American Economic Review* 88:463–7.
- Eason, Perri K., Gary A. Cobbs, and Kristin G. Trinca. 1999. The use of landmarks to define territorial boundaries. *Animal Behaviour* 58:85–91.
- Eck, John E. 1994. *Drug Markets and Drug Places: A Case-Control Study of the Spatial Structure of Illicit Drug Dealing*. College Park: University of Maryland Press.
- Fleisher, Mark S. 1998. *Dead End Kids: Gang Girls and the Boys They Know*. Madison: University of Wisconsin Press.
- Gaston, Kevin J. 2009. Geographic range limits: Achieving synthesis. *Proceedings of the Royal Society B-Biological Sciences* 276:1395–406.
- Golub, Gene H., and Charles F. Van Loan. 1980. An analysis of the total least squares problem. *SIAM Journal on Numerical Analysis* 17:883–93.
- Greenbaum, Robert T., and George E. Tita. 2004. The impact of violence surges on neighbourhood business activity. *Urban Studies* 41:2495–514.
- Griffiths, Elizabeth, and Jorge M. Chavez. 2004. Communities, street guns and homicide trajectories in Chicago, 1980–1995: Merging methods for examining homicide trends across space and time. *Criminology* 42:941–78.

- Hagedorn, John M. 1988. *People and Folks: Gangs, Crime and the Underclass in a Rustbelt City*. Chicago, IL: Lakeview Press.
- Hagedorn, John M. 1994. Neighborhoods, markets, and gang drug organization. *Journal of Research in Crime and Delinquency* 31:264–94.
- Harocopos, Alex, and Michael Hough. 2005. *Drug Dealing in Open-air Markets* (Problem Specific Guides Series). Washington, DC: U.S. Department of Justice.
- Jacobs, Bruce A., and Richard T. Wright. 2006. *Street Justice: Retaliation in the Criminal Underworld*. Cambridge, U.K.: Cambridge University Press.
- Jankowski, Jill E., Scott K. Robinson, and Douglas J. Levey. 2010. Squeezed at the top: Interspecific aggression may constrain elevational ranges in tropical birds. *Ecology* 91:1877–84.
- Johnson, Neil F., Chen Xu, Zhenyuan Zhao, Nicholas Ducheneaut, Nicholas Yee, George Tita, and Pak M. Hui. 2009. Human group formation in online guilds and offline gangs driven by a common team dynamic. *Physical Review E* 79:066117.
- Kennedy, David M., Anthony A. Braga, and Anne M. Piehl. 2001. *Reducing Gun Violence: The Boston Gun Project's Operation Ceasefire Series* (Research Report). Washington, DC: National Institute of Justice.
- Klein, Malcom W. 1995. *The American Street Gang: Its Nature, Prevalence, and Control*. New York: Oxford University Press.
- Klein, Richard G. 1995. Anatomy, behavior and modern human origins. *Journal of World Prehistory* 9:167–98.
- Ley, David, and Roman Cybriwsky. 1974. Urban graffiti as territorial markers. *Annals of the Association of American Geographers* 64:491–505.
- Liebow, Elliot. 1967. *Tally's Corner*. Boston, MA: Little, Brown.
- Maxson, Cheryl L. 1995. *Street Gangs and Drug Sales in Two Suburban Cities* (Research in Brief). Washington, DC: U.S. Department of Justice, Office of Justice Programs, National Institute of Justice.
- Maxson, Cheryl L. 2011. Street gangs. In *Crime and Public Policy*, eds. James Q. Wilson and Joan Petersilia. New York: Oxford University Press.
- Moorcroft, Paul R., Mark A. Lewis, and Robert L. Crabtree. 2006. Mechanistic home range models capture spatial patterns and dynamics of

- coyote territories in Yellowstone. *Proceedings of the Royal Society B: Biological Sciences* 273:1651–9.
- Moore, Joan W. 1978. *Homeboys: Gangs, Drugs and Prison in the Barrios of Los Angeles*. Philadelphia, PA: Temple University Press.
- Moore, Joan W., Diego Vigil, and Robert Garcia. 1983. Residence and territoriality in Chicano gangs. *Social Problems* 31:182–94.
- Nattermann, Thomas, Yonathan Shapir, and Igor Vilfan. 1990. Interface pinning and dynamics in random systems. *Physical Review B* 42:8577.
- Olzak, Susan. 1994. *The Dynamics of Ethnic Competition and Conflict*. Stanford, CA: Stanford University Press.
- Otto, Sarah P., and Troy Day. 2007. *A Biologist's Guide to Mathematical Modeling in Ecology and Evolution*. Princeton, NJ: Princeton University Press.
- Papachristos, Andrew V. 2009. Murder by structure: Dominance relations and the social structure of gang homicide. *American Journal of Sociology* 115:74–128.
- Patillo-McCoy, Mary. 1999. *Black Picket Fences: Privilege and Peril among the Black Middle Class*. Chicago, IL: University of Chicago Press.
- Radil, Steven M., Colin Flint, and George E. Tita. 2010. Spatializing social networks: Using social network analysis to investigate geographies of gang rivalry, territoriality, and violence in Los Angeles. *Annals of the Association of American Geographers* 100:307–26.
- Rengert, George F. 1996. *The Geography of Illegal Drugs*. Boulder, CO: Westview Press.
- Rosenfeld, Richard, Timothy M. Bray, and Arlen Egley. 1999. Facilitating violence: A comparison of gang-motivated, gang-affiliated, and non-gang youth homicides. *Journal of Quantitative Criminology* 15:495–516.
- Sanchez-Jankowski, Martin S. 1991. *Islands in the Street: Gangs and American Urban Society*. Berkeley: University of California Press.
- Senese, Paul D., and John A. Vasquez. 2003. A unified explanation of territorial conflict: Testing the impact of sampling bias, 1919–1992. *International Studies Quarterly* 47:275–98.
- Short, Martin B., P. Jeffrey Brantingham, Andrea L. Bertozzi, and George E. Tita. 2010. Dissipation and displacement of hotspots in

- reaction-diffusion models of crime. *Proceedings of the National Academy of Sciences* 107:3961–5.
- Sibley, David, and Bettina Van Hoven. 2009. The contamination of personal space: Boundary construction in a prison environment. *Area* 41:198–206.
- Smith, Laura M., Andrea L. Bertozzi, P. Jeffrey Brantingham, George E. Tita, and Matthew Valasik. 2012. Adaptation of an animal territory model to street gang spatial patterns in Los Angeles. *Discrete and Continuous Dynamical Systems* 32:3223–44.
- Spergel, Irving, David Curry, Ron Chance, Candice Kane, Ruth Ross, Alba Alexander, Edwina Simmons, and Sandra Oh. 1996. Gang suppression and intervention: Problem and response. Washington, DC: Office of Juvenile Justice and Delinquency Prevention, U.S. Department of Justice.
- Sullivan, Mercer L. 1989. *Getting Paid: Youth Crime and Work in the Inner City*. Ithaca, NY: Cornell University Press.
- Sutter, Daniel. 1995. Asymmetric power relations and cooperation in anarchy. *Southern Economic Journal* 63:602–13.
- Taniguchi, Travis A., Jerry H. Ratcliffe, and Ralph B. Taylor. 2011. Gang set space, drug markets, and crime around drug corners in Camden. *Journal of Research in Crime and Delinquency* 48:327–68.
- Taylor, Ralph B., and Sidney Brower. 1985. Home and near-home territories. In *Human Behavior and Environment, Vol. 8, Home Environments*, eds. I. Altman and C. Werner. New York: Plenum.
- Temeles, Ethan J. 1994. The role of neighbours in territorial systems: When are they ‘dear enemies’? *Animal Behaviour* 47:339–50.
- Thornberry, Terence P., Marvin D. Krohn, Alan J. Lizotte, Carolyn A. Smith, and Kimberly Tobin. 2003. *Gangs and Delinquency in Developmental Perspective*. New York: Cambridge University Press.
- Thrasher, Frederick M. 1927. *The Gang: A Study of 1313 Gangs in Chicago*. Chicago, IL: University of Chicago Press.
- Tita, George E., Jacqueline Cohen, and John Engberg. 2005. An ecological study of the location of gang “set space.” *Social Problems* 52:272–99.
- Tita, George, and Greg Ridgeway. 2007. The impact of gang formation on local patterns of crime. *Journal of Research in Crime and Delinquency* 44:208–37.

- Tita, George, K. Jack Riley, Greg Ridgeway, Clifford Grammich, Allan F. Abrahamse, and Peter W. Greenwood. 2003. *Reducing Gun Violence: Results from an Intervention in East Los Angeles*. Santa Monica, CA: RAND.
- Turchin, Peter. 2003. *Historical Dynamics: Why States Rise and Fall*. Princeton, NJ: Princeton University Press.
- Valdez, Avelardo, Alice Cepeda, and Charles Kaplan. 2009. Homicidal events among Mexican American street gangs. *Homicide Studies* 13:288–306.
- Vasquez, John, and Marie T. Henahan. 2001. Territorial disputes and the probability of war, 1816–1992. *Journal of Peace Research* 38:123–38.
- Venkatesh, Subir A. 1997. The social organization of street gang activity in an urban ghetto. *American Journal of Sociology* 103:82–111.
- Vigil, James Diego. 1988. *Barrio Gangs: Street Life and Identity in Southern California*. Austin: University of Texas Press.
- Werthman, Carl, and Irving Piliavin. 1967. Gang members and the police. In *The Police: Six Sociological Essays*, ed. David Bordua. New York: Wiley.
- Whyte, William F. 1955. *Street Corner Society: The Social Structure of an Italian Slum*. Chicago, IL: University of Chicago Press.
- Wootton, J. Timothy, and Mark Emmerson. 2005. Measurement of interaction strength in nature. *Annual Review of Ecology Evolution and Systematics* 36:419–44.
- Ydenberg, Ronald C., Luc-Alain Giraldeau, and J. Bruce Falls. 1988. Neighbours, strangers, and the asymmetric war of attrition. *Animal Behaviour* 36:343–47.

P. Jeffrey Brantingham is a professor of anthropology at UCLA. His research interests include human use of space, offender target selection, and mathematical modeling.

George E. Tita is an associate professor in the Department of Criminology, Law and Society at the University of California—Irvine. His research interests include the community context of crime, modeling the social and geographic dimensions of urban street gangs, and the design and evaluation of crime reduction strategies.

Martin B. Short is an assistant adjunct professor of mathematics at UCLA. His research interests include modeling complex systems, partial differential equations, and game theory.

Shannon E. Reid is a doctoral student in the Department of Criminology, Law and Society at the University of California—Irvine. She received a Master's in Justice, Law and Society (M.S.), from the School of Public Affairs, American University.