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ORIGINAL PAPER

The Emergence and Evolution of Problematic Properties: Onset, Persistence, Aggravation, and Desistance

Daniel T. O'Brien[1,2,3] · **Alina Ristea**[1,3] · **Riley Tucker**[2,3] · **Forrest Hangen**[1,3]

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Abstract

Objectives Scholars and practitioners have paid increasing attention to problematic properties, but little is known about how they emerge and evolve. We examine four phenomena suggested by life-course theory that reflect stability and change in crime and disorder at properties: *onset* of issues; *persistence* of issues; *aggravation* to more serious types of issues; and *desistance* of issues. We sought to identify the frequency and dynamics of each.

Methods We analyze how residential parcels (similar to properties) in Boston, MA shifted between profiles of crime and disorder from 2011 to 2018. 911 dispatches and 311 requests provided six measures of physical disorder, social disorder, and violence for all parcels. K-means clustering placed each parcel into one of six profiles of crime and disorder for each year. Markov chains quantified how properties moved between profiles year-to-year.

Results Onset was relatively infrequent and more often manifested as disorder than violence. Pathways of aggravation led from less serious profiles to a mixture of violence and disorder. Desistance was more likely to occur as de-escalations along these pathways then complete cessation of issues. In neighborhoods with above-average crime, persistence was more prevalent whereas desistance less often culminated in cessation, even relative to local expectations.

Conclusions The results offer insights for further research and practice attentive to trends of crime and disorder at problematic properties. It especially speaks to the understanding of stability and change; the role of different types of disorder; and the toolkit needed for problem properties interventions.

Keywords Problem properties · Criminology of place · Communities and crime · Urban criminology · Quantitative methods · Developmental criminology

✉ Daniel T. O'Brien
d.obrien@neu.edu

[1] School of Public Policy and Urban Affairs, Northeastern University, 310 Renaissance Park, 1135 Tremont St., Boston, MA 02120, USA

[2] School of Criminology and Criminal Justice, Northeastern University, Boston, USA

[3] Boston Area Research Initiative, Northeastern and Harvard Universities, Boston, USA

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Introduction

In recent years criminologists have increasingly turned their attention to individual properties. Intellectually, research has revealed that crime and disorder tend to concentrate at a small number of properties (e.g., O'Brien 2019; Farrell and Pease 2001; Johnson et al. 2007; Eck et al. 2007). Practically, city officials and police departments have adopted policy tools that identify and respond to "problem properties" (Way et al. 2013; LISC 2019; Boston 2011). As we better grasp the nature and types of problematic properties, there remain open questions about how they emerge and evolve over time. Where there has been longitudinal research on the subject, it is generally on the long-term persistence of a particular form of crime or disorder. There has been little if any examination of more nuanced trajectories, such as a property manifesting different types of problems or alternating between being problematic or not, and whether these patterns are systematic and predictable.

The question of how crime and disorder evolve over time at properties parallels the subfields of life-course and developmental criminology (Sampson and Laub 1993; Le Blanc and Loeber 1998), which have long studied patterns of stability and change in people. Though these literatures are crafted around the developmental processes that constitute the stages of a person's life, which are distinct from the processes underlying crime and disorder at properties (see also Sherman 1995), they do offer guidance regarding the types of phenomena that merit attention, including: the *onset* of crime or disorder; *persistence* of crime and disorder across time; *aggravation*, or escalation of crime and disorder; and *desistance*, or the diminishment of crime and disorder, including cessation of all issues. Here we examine the prevalence and dynamics of these four phenomena, making two contributions. First, the most prominent work on trajectories of places has concentrated on persistence in a single type of crime (e.g., Weisburd et al. 2012), whereas frameworks on the role of disorder implicate aggravation (e.g., Wilson and Kelling 1982). Here we examine the mixture and severity of issues at a place, allowing us to better observe onset and desistance, which have been understudied. Second, we consider how the dynamics of each of these four phenomena might differ based on the level of crime in the surrounding neighborhood.

We present an examination of onset, persistence, aggravation, and desistance in residential parcels (i.e., individual building lots containing one or more properties; akin to addresses) in Boston, MA over an 8-year period; we focus on residential properties to guard against the possibility that these phenomena exhibit distinct patterns across land uses, which would require independent analyses. We first use cluster analysis to classify every parcel in each year according to the mixture of physical disorder, social disorder, and violent crime occurring there. This technique enables an analysis of how properties do or do not shift between profiles of issues over the study period, thereby illustrating all four phenomena suggested by life-course theory. Before proceeding to the data and analyses, the following subsections summarize existing work on longitudinal patterns of crime and disorder at properties as well as other geographic scales of analysis, including streets and neighborhoods; present the four phenomena of stability and change in greater detail, including associated hypotheses; and elaborate on the empirical logic of the study.

Stability and Change at Properties (and Other Geographic Scales)

Research on crime and disorder at properties is part of the broader study of crime at places, including properties, institutions, and street segments. Longitudinal studies in this vein have mainly addressed two phenomena: *persistence*, or stability in the frequency or severity of crime and disorder; and *aggravation*, or escalation to issues of greater frequency or severity. As we summarize, the former line of research has consisted primarily of studies on how a single type of crime or disorder has continued over time at places, especially hotspot streets. The latter has concentrated on how disorder might encourage or lead to crime, albeit primarily at the neighborhood or community scale. Although there is reason to believe that there are different criminogenic processes at these different scales of analysis (Jones and Pridemore 2019), the summary that follows also includes work on neighborhoods here given its similar geographic focus.

Criminologists have long recognized that crime and disorder tend to persist in the same neighborhoods over time (Shaw and McKay 1942/1969; Sampson 2012; Wilson 1987). More recent work by criminologists of place have extended this insight to hotspot streets, leveraging group-based trajectories to track how crime concentrates on a small handful of streets in a city across years and even decades (Groff et al. 2010; Weisburd et al. 2004, 2012; Braga et al. 2011, 2010). These studies have demonstrated that street segments tend to maintain a characteristic level of crime, be it high, moderate, low, or none. At the property level, studies of repeat victimization have also shown that certain people and places tend to experience the same type of crime multiple times (Farrell and Pease 2001; Frank et al. 2012; Johnson et al. 1997; Levy and Tartaro 2010; Reiss 1980), even arguing that the first such event may increase the likelihood of future ones (Johnson 2008). One additional study found that multiple forms of disorder and crime all persisted from year to year at the address, street, and neighborhood levels simultaneously, even when controlling for persistence at the other two levels (O'Brien and Winship 2017). Overall, these efforts have been illuminating regarding persistence, but, as we return to later, they have largely set aside the non-trivial proportion of streets that saw shifts in the level of crime over the study period.

Research on aggravation in communities and at places has focused on whether physical and social disorder lead to more serious incidents. The most well-known such perspective is broken windows theory (BWT), which argues that the prevalence of physical and social disorder in public spaces encourages further delinquency and violent crime (Wilson and Kelling 1982). This has been joined by corollary theories that also argue that disorder can lead to crime but via other mechanisms; for example, that certain types of physical disorder create "ecological advantages" that make crime easier to commit (e.g., abandoned buildings offer hiding places for contraband; St. Jean 2007; Branas et al. 2016). An alternative perspective, known as social escalation theory (SET) is that *private* disorder, rather than public disorder, is more likely to lead to violence in a neighborhood. O'Brien and Sampson (2015) argued that domestic disputes and conflicts between neighbors can become increasingly violent and spill out into public spaces if not defused.

Regardless of the theory, empirical work on how disorder can lead to crime has almost exclusively occurred at the neighborhood level. BWT has been studied at this scale for nearly 40 years through a variety of methodologies, including cross-sectional and longitudinal observational studies (e.g., Sampson and Raudenbush 1999; Taylor 2001) and evaluations of policing interventions that focused on the removal of disorder (see Weisburd et al. 2015a, b for a review). These have often found mixed results. There are however, a handful of studies that have found evidence for BWT at the more localized scale of streets. Wheeler

(2017) saw that disorder on a street was predictive of future crime. Braga and Bond (2008) also found evidence that a randomized control trial that cleared disorder succeeded in lowering crime on target streets. Meanwhile, ecological advantages have largely been studied at the street segment level because the theory specifically implicates the ways that a particular piece of disorder, like an abandoned building, can facilitate crime in the immediate surrounding area (Branas et al. 2016; Furr-Holden et al. 2011). Likewise, SET has only been demonstrated, to our knowledge, at the neighborhood level (O'Brien and Sampson 2015). That said, it draws on a variety of evidence at the individual and household level that would suggest more localized relationships are possible or even likely. For instance, household conflict and community violence can be instigated by the same individuals (Kiss et al. 2015), or the former can feed into stressors that facilitate the latter (Caughy et al. 2012).

In addition to work on crime and disorder over time at addresses, streets, and neighborhoods, a small set of studies has also examined how the presence of crime throughout a community can reinforce the persistence of crime at places therein. Repeat victimization, for example, is even more likely for people and places in high-crime communities (Trickett et al. 1995; Johnson et al. 1997). Meanwhile, O'Brien and Winship (2017) found that persistence at an address was greater if its street or tract also had above-average levels of crime. We might, then, expect to see the same reinforced persistence when analyzing the criminal careers of places. It also raises the possibility that reinforcement can make aggravation more likely, though this has not been studied.

Existing research on persistence and aggravation lays a strong foundation for understanding how problematic properties emerge and evolve. It also suggests that there might be an important interplay between places and their communities. Nonetheless, current knowledge is incomplete. As the next section will articulate, life-course theory suggests some additional phenomena regarding change in crime and disorder that have received little if any attention.

Describing Change and Stability in Crime and Disorder: Four Phenomena

In an early essay, Sherman (1995) compared the "criminal careers" of people and places. As he did then, we argue that life-course theory and developmental criminology hold lessons for examining, understanding, and addressing how crime and disorder emerge and evolve at problematic places. We note, however, that we use this largely as an analogy. Life-course and developmental criminology operate on the premise that offending behavior interacts with the social and psychological developmental processes that underlie the pathway from youth to adolescence to adulthood (Le Blanc and Loeber 1998). Meanwhile, Sherman (1995) has pointed out that longitudinal trends in crime and disorder at places are likely governed by shifts in routine activities—that is, the comings and goings of potential offenders, victims, and guardians and their purposes for being there (Cohen and Felson 1979)—and other contextual factors associated with crime, like the demographics and social organization of the broader community (Sampson 2012). Though the latter can certainly account for shifts in crime and disorder over time, owing to changes in ownership, residents, visitors, management, or otherwise, the underlying processes will be quite different. Thus, here we leverage the deep history of studying people's life courses in offending to suggest four phenomena that describe stability and change in properties: in addition to

persistence and *aggravation* we also consider *onset* and *desistance*. We elaborate on each and the corollary questions in turn.

Onset

The beginning of a criminal career is the *onset* of crime, and the earlier it occurs the greater an individual's propensity and long-term opportunities for crime (Farrington et al. 1990; Moffitt 1993). The age of a place has less meaning in these regards, but onset is still a salient moment in which crime and disorder first appear at a property, setting the stage for future increases or decreases in issues. The study of onset for places has largely been through work on the trajectories of crime for street segments, though this has been indirect. For example, Weisburd et al. (2004) identified a substantial proportion of streets in Seattle, WA with increasing trajectories, some of which had not had crime previously. The work did not, however, flag them as such nor analyze their characteristics. One challenge is that it can be difficult to bound the history of a place in a way that ensures we are observing "onset"; for instance, if there was a shooting at a property 30 years ago and another last week, is that a new onset or a re-emergence of crime? For this reason, we define onset as the appearance of crime where there was none at the previous timepoint, though recognizing that this is subject to the time scale of analysis.

A major initial question is whether certain profiles of crime and disorder are more likely to occur at the point of onset. Being that onset of crime in youth typically occurs with a low-level offense (Le Blanc and Frechette 1989), it would seem the same gradual emergence could be true for places. We thus hypothesize that onset entails less severe kinds of issues, like disorder. This would seem to be likely regardless of whether it is truly the first onset of issues at a place or a transition from a temporary lack of issues.

Persistence

Developmental criminologists refer to *activation* as the process by which a criminal career is established, including the stabilization of a criminal habit (Le Blanc and Loeber 1998). At a property, such stabilization might be observed as the *persistence* of crime and disorder. Given that land use, demographics, routine activities, and social dynamics all tend to be stable for extended periods of time, it would seem that persistence might be the most common of the four phenomena identified here. It is also the most studied to date. A major consideration for persistence is whether stability is uniform across types of crime and disorder, or whether some are more likely to give way to further shifts in the criminal career of a place. We view this as an open empirical question. In addition, the availability of 8 years of data enables us to examine how durable persistence is. We hypothesize that as a parcel exhibits the same profile of crime and disorder for more consecutive years, it is increasingly likely to remain that way in the following year.

Aggravation

Aggravation, or a sequence of escalation that an offender can pass through, might include increases both in the seriousness of events (Sellin and Wolfgang 1964) and their variety (Blunstein et al. 1986; Hindelang et al. 1981). As summarized in the previous section, multiple theories have posited the same for places, with disorder acting as the agent of aggravation, eliciting or instigating more serious issues. Here we probe three questions. First

and most simply, how frequently does aggravation occur? Second, which pathways from one type of issue to another are most common? This is a novel test of BWT and SET's arguments that public and private disorder, respectively, tend to evolve into more serious events. Third, are there extended, multistep pathways to more severe issues? This last question is testable thanks to the extended corpus of data available.

Desistance

Desistance, or a decrease in the frequency or severity of crime and disorder, is the concluding stage in any crime career—and critical for crime prevention. Research on desistance at places has been understudied. This is explained by both conceptual and methodological limitations. Conceptually, theories of aggravation from disorder to crime do not include stipulations about de-escalation. Methodologically, studies on shifts from disorder to crime have traditionally employed regressions that use counts of events of disorder to predict the subsequent emergence of crime. Using regressions to reveal the presence of disorder following the cessation of serious crime, however, would be convoluted. The question then lends itself more to the analysis of trajectories. For instance, one study found some (but not overwhelming) overlap between streets that had stable, high levels of disorder and those with stable, high levels of crime (Yang 2010). Also, as with onset, it can be difficult to ascertain the point of "true" desistance as we would need data for the full time period that a place exists. For our analysis, we proceed by defining desistance as the absence of issues following a period in which issues were present, though we cannot be fully confident that this absence continued into future time periods.

Importantly, desistance need not be an all-or-nothing concept. Kazemanian (2007) points out that, although desistance is often equated to cessation of crime, it is a nuanced process by which an individual gradually diminishes the severity and frequency of offending. We adopt this perspective for places, whose routine activities and other characteristics are also more likely to undergo gradual shifts. Importantly, trajectory studies have not differentiated between partial and complete desistence. We hypothesize that places with high-severity issues will more often transition to less severe issues than experiencing complete and immediate cessation. Second, we hypothesize that the steps to desistance will tend to be a mirror image of aggravation. If, as we have noted, we assume that a place retains many of its underlying qualities over time, they would be likely to revert to similar forms of crime and disorder during the process of desistance. Again, we will be careful to note that we are analyzing a time period that does not continue through the full time period that the property exists, limiting our certainty that the de-escalation or elimination of issues is permanent.

Neighborhood Context

As noted above, there is a growing body of evidence that the presence of elevated crime in a community can reinforce the persistence of crime at places therein (Trickett et al. 1995; Johnson et al. 1997; O'Brien and Winship 2017). We hypothesize that high-crime contexts will affect other parts of the criminal career as well. It will reinforce persistence and aggravation, as criminogenic dynamics in the neighborhood will either directly contribute to or antagonize crime and disorder at places. Similarly, if desistance proves to be a multipart process, we hypothesize that higher crime contexts will slow the realization of cessation.

Current Study

Many studies on longitudinal trajectories in crime and disorder, whether on individuals or places, generate typologies that classify units of analysis according to the timing and shape of the different stages that constitute a criminal career (e.g., Nagin and Land 1993; Weisburd et al. 2004). We adopt a similar strategy here as we conduct a prospective analysis of all residential parcels (similar to properties or addresses) in Boston, MA for 2011–2018, though with a distinctive two-part analytic approach. This is necessary owing to our goal of moving beyond previous studies on the crime trajectories of places, most notably those conducted in Seattle, WA by Weisburd et al. (2004, 2012) and Yang (2010), which have examined a single measure of crime. Here we instead examine shifts in the types or variety of issues at a place by leveraging six established measures from administrative records collected by city agencies: physical disorder in private and public spaces, social disorder in private and public spaces, and violent crime and prevalence of guns (O'Brien et al. 2015; O'Brien and Sampson 2015).

Part one of the analysis creates a typology for profiles of crime and disorder and part two observes how parcels shift between these profiles over time. To illustrate, a property that falls into a "high physical disorder" category in year one might shift into a "high social disorder" category in year two. Operationally, the first stage consists of a cluster analysis that uses the six measures of disorder and crime to categorize all parcels in each year according to their profile of crime and disorder. There are debates about the appropriateness of typological analyses (Eggleston et al. 2004; Nagin and Tremblay 2005), especially regarding the concern that such methods will find typologies even if the resultant groupings have no real-world meaning. There are statistical and theoretical reasons to believe that this is not a concern in the current case. Statistically, the six forms of crime and disorder do not correlate highly at the parcel level ($rs < 0.2$), making it harder to segment parcels into spurious groupings. Theoretically, as argued above, routine activities theory suggests that it is unlikely that all problematic places feature the same expression of crime and disorder. Instead, the specific types of offenders, targets, and guardians that frequent a place and their purposes for being there will determine the types of issues that occur, giving rise to multiple profiles of crime and disorder.

The second stage of the analysis uses Markov chain models to observe when properties transition from one type to another between years, quantifying which transitions are occurring more often than would be likely by chance. Markov chain models have been used by developmental criminologists as an ideal tool for examining longitudinal transitions in offending behavior (Lattimore et al. 1994; Pettiway et al. 1994; Stander et al. 1989; Merlone et al. 2016), but the same analytic logic has not been applied to evolution and emergence of crime at places (though see a related application to the diffusion of riots across space; Baudains et al. 2013). Here they will assess year-to-year transitions as well as 3-year sequences, which will better reveal both the durability of stability, either in the form of persistence or the absence of crime, as well as the shape of multipart transitions, like aggravation and desistance. We also segment these analyses by neighborhoods to examine the role of the community in shaping the emergence and evolution of crime and disorder at places. Distinct from previous work, this analytic design is well-suited for independently observing the frequencies of onset, persistence, aggravation, and desistance and the forms that each is most likely to take. Importantly, it avoids the weaknesses of allowing persistence to predominate models as the most common trend for crime at places; and of lumping onset and aggravation as "increasing"

trajectories and different gradients of desistance as "decreasing" trajectories. Additionally, as noted in the previous section, desistance is difficult to specify with a regression framework. Here, however, we will be able to observe how often a property exhibiting, for example, a concentration of violence transitions into one with only physical disorder.

Last, our sample is all residential parcels in the city. Despite the semantic and practical focus on "properties" in the literature, "parcels"—identifiable lots that contain one or more properties are very similar to addresses—are the lowest level for reliably attributing events to places, making them the optimal unit of analysis (see "Methods" section for more). Also, we limit our attention to residential parcels, excluding commercial, industrial, and exempt land uses. Each land use has its own characteristic types of routine activities and as a result could exhibit for each of the phenomena observed here, thereby complicating analyses and interpretations. For this reason, we start with residential parcels as the most numerous locations in the city (~80% of parcels) and anticipate that the work should be replicated with other types of places.

Methods

Data sources

The study utilizes two archives of administrative records from the City of Boston for 2011–2018: dispatches made by the 911 system, which capture events referencing social disorder and violent crime; and requests for non-emergency services received by 311, which capture physical disorder in private and public spaces. All records include date and time when the issue was registered, the location of the issue, and a case type categorizing the issue.

Unit of Analysis and Geographic Coordination

The unit of analysis is the land parcel (i.e., lots that contain one or more properties), which are the fundamental unit of the urban landscape and an approximation of the colloquial "address."[1] Land parcels are nested in census tracts. This organization is made possible by mapping the City of Boston's list of land parcels and then condensing them slightly by combining distinct land parcels with the same postal address that are sufficiently close to each other as to be indistinguishable in the data.

From 2011 to 2018 the City of Boston made 5,356,049 unique 911 dispatches and received 1,686,459 requests for service through 311, including the latitude and longitude of the location of each event. We used this information to spatially join to the nearest land parcel. This process was able to attribute 4,978,558 911 reports to an address (93% geocoding rate; 6% of records lacked lat-long and 1% fell outside city boundaries) and 1,482,040 311 reports were mapped to the nearest known parcel at the time of data entry (others had no relevant geographic information or were mapped to City Hall as a default; 88%

[1] Parcels contain one or more properties (e.g., condo buildings are parcels with a separate property for every unit; *mean* = 1.82 properties, *sd* = 7.88, 88% had 1 property, but 171 (0.2% of parcels) had more than 50). However, in official records of events the most granular piece of information is the street address, which does not distinguish between properties within a parcel. For this reason, it is necessary to treat parcels as the most fundamental unit available to analysis.

Table 1 Distribution of the six measures of disorder and crime across residential parcels, including the total count of events, mean events per parcel, and the percentage with at least 1 event from 2011 to 2018

Measure	Social disorder	Private conflict	Violence	Guns	Private neglect	Public denig
Counts	12,697	55,065	62,173	12,072	59,517	72,671
Mean per parcel	0.16	0.67	0.76	0.15	0.73	0.89
Std. dev. (parcels)	0.95	1.86	2.85	0.65	2.51	3.04
% parcels w/1 + events	9.5%	29.2%	26.2%	9.1%	23.0%	29.0%

Analysis limited to the 81,673 parcels with residential land use classifications

geocoding rate). Geocoding rates for the case types used in the study (see "Measures" section) were 98% for 911 dispatches and 92% for 311 requests.

We limited the analysis to the 81,673 parcels with residential land usage [of 98,136 total; see Supplementary Online Materials (SOM)]. These include single-family (R1; 37%), two-family (R2; 21%), three-family (R3; 17%), four-family (R4; 3.1%), apartment buildings (seven or more units; 3.0%), condominiums (10.7%), and condo lobbies (0.03%). We limited to residential parcels to maintain a certain level of homogeneity in routine activities, otherwise a typological analysis would be likely to differentiate primarily on land use. Further, it is possible that questions of dynamics of change and stability vary considerably between residential parcels and other land uses, which would complicate the interpretation of this initial study.

Measures

We used six measures of physical disorder, social disorder, and violent crime (see SOM for all case types and frequencies). We drew two indices of physical disorder from 311 requests (O'Brien et al. 2015): *private neglect*, comprised of cases referencing housing issues, uncivil use of private spaces, and problems with big buildings (59,517 reports); and *public denigration*, comprised of cases reflecting graffiti and the improper disposal of trash (72,671 reports). Measures of social disorder and violent crime were drawn from 911 dispatches (O'Brien and Sampson 2015). The two indices of social disorder were *public social disorder* (e.g., panhandlers, public drunkenness; 12,697 reports), and *private conflict* arising from personal relationships (e.g., landlord-tenant conflicts; 55,065 reports). The indices of violent crime were *public violence* that did not involve a gun (e.g., fight; 62,173 reports) and *prevalence of guns*, as indicated by shootings or other incidents involving guns (12,172 reports). We tabulated events reflecting each of these six types of crime and disorder at each parcel in each year (see Table 1 for distribution). These are the main measures used in the analyses that follow.

Analysis Plan

Typologies of Properties

We created typologies of residential properties based on their profile of crime and disorder events using K-means clustering. K-means is an unsupervised machine learning technique that categorizes a collection of n entities (i.e., parcels) into k groups based on a set of variables. k is pre-determined by the analyst. K-means begins with an initial set of k

randomly-generated centroids (or "means") and then categorizes every point in n according to the nearest of these means in Euclidean distance (i.e., partitioning space into k Voronoi cells). It then adjusts each of the k means to be the centroid of the cases attributed to it and uses the new means to reclassify all objects in n. This process repeats until convergence (i.e., there is no change in the categorization of any member of n). The goal of K-means clustering is to minimize the within-cluster variance (i.e., $\min(\sum_{i=1}^{k} \sum_{x \in S_i} |x - \mu_i|^2)$ where S_i is a member of one of the k categories), in turn maximizing variance across clusters, for a given value of k.

Because K-means defines categories based on the correlation structure of the data, it is not driven by a pre-specified equation or model. The analyst only needs to specify the variables of interest and the value of k (i.e., the number of categories to be defined). In this case, the variables were the six categories of disorder and crime, each normalized before analysis. The unit of analysis was parcel-years (i.e., each parcel in each year was treated as an independent event that could take on a different profile of crime and disorder), for a sample of 653,384 (8 years * 81,673 parcels). There is no definitive way to determine the optimal number of clusters, but the algorithm generates diagnostics for solutions for every value of k up to 10. We used three popular techniques for interpreting this information, as described in the SOM, electing to set $k = 6$.

Trajectories of Problematic Properties

We used Markov Chain models to describe how properties transition between profiles of crime and disorder from year to year. Markov chains are a random process that consists of: a *state space*, or the profiles of crime and disorder that a parcel might experience; a *transition matrix* describing the probabilities of transitions between states; and an initial distribution of states (Gagniuc 2017). Markov chains are characterized by a memoryless property, wherein a future state depends only on the current state. This is represented mathematically as $P(q_i = a|q_1, q_2, \ldots, q_{i-1}) = P(q_i = a|q_{i-1})$, where q_i is the state of object q at timepoint i and a is a specific state in the state space; that is, the immediately previous state of an object is all the information necessary for predicting its state at the current time. This logic can be generalized to chains of size n where the final state is modeled as a function of the preceding $n-1$ states (i.e., $P(q_i = a|q_1, q_2, \ldots, q_{i-1}) = P(q_i = a|q_{i-n}, \ldots, q_{i-1})$). The transition probability matrix is then represented as, $A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$, where a_{ij} is the probability that an object beginning in state i will transition to state j at the next time point. Markov chain analyses use shifts observed in the data to calculate estimates and standard errors for all the values in the transition probability.

We conducted two Markov chain analyses using the *markovchain* package in R (Spedicato 2017). As with K-means clustering, the technique extracts the transition matrix directly from the data without any pre-determined model; the analyst only specifies the unit of analysis and transitions. First, we conducted a traditional Markov chain calculating the probabilities that a parcel with a given profile of crime and disorder in 1 year exhibited each of the other possible profiles of crime and disorder in the next year. Second, we conducted a second-order transition probability matrix that modeled the current state of a parcel on the states in the previous 2 years (i.e., $P(q_i = a|q_1, q_2, \ldots, q_{i-1}) = P(q_i = a|q_{i-1}, q_{i-2})$. We refer to these two analyses as 2-year and 3-year Markov chains throughout the analysis. In

each case we used the maximum likelihood estimation method, which generates standard errors for each a_{ij}.

To better interpret the probability matrices, we re-ran the analyses by randomizing the distribution of parcels across states within each year (i.e., keeping the annual proportions of states but removing their non-random associations within parcels across years). This produced year-to-year transitions completely consistent with randomness (i.e., each a_{ij} was equal to the proportion of parcels exhibiting state j), and the maximum likelihood procedure for the Markov chains produced standard errors for the variability in outcomes associated with that randomness. We repeated this process 100 times, calculating the mean of the transition matrix estimates and of the standard errors of these estimates to evaluate the magnitude of differences between our observed and expected outcomes. We compared these randomized results with the actual results in two ways. First, we calculated relative odds ratios of the form $OR = \frac{a_{ij_a}}{(1-a_{ij_a})} \Big/ \frac{a_{ij_e}}{(1-a_{ij_e})}$ where a_{ij_a} and a_{ij_e} are from the transition probability matrices for the actual and randomized data, respectively. This offers an interpretable effect size of a given transition's deviation from expectations. Second, we used the estimated standard errors to calculate t tests for whether the actual and expected likelihoods were significantly different.

Results

Descriptive Statistics

From 2011 to 2018, 59.5% of parcels generated no crime or disorder per our six measures. The remaining parcels were almost evenly split between those who experienced only one type of issue (19.9%) and those that had at least one instance of two or more type of issues (20.6%). Only 0.06% experienced issues from all six categories of crime and disorder.

Confining to parcels with two or more type of issues, we found that over half of them included either of two combinations: 29.0% had a combination of private neglect and public denigration, and 27.7% had a combination of violence and private conflict. Other combinations over 10% were: private conflict and private neglect (16.5%); violence and private neglect (13.1%); private conflict and public denigration (12.8%); and violence and public denigration (11.9%). Though potentially informative, these proportions are difficult to interpret as they are subject to the relative frequencies of the six categories of crime and disorder; for instance, guns were the rarest event type and not included in any of the combinations.

Cluster Analysis

We applied K-means cluster analysis to the six measures of interest with parcel-year as the unit of analysis, thus treating each parcel as capable of expressing a different profile of crime and disorder in each year. Using diagnostic tests (see Appendix B), we determined that six was the optimal number of clusters. We organize the six clusters, whose characteristics are described in Table 2, into three groupings, ordered both in terms of their

Table 2 Profiles of crime and disorder generated by K-means cluster analysis, their frequency across parcel-years, and the mean incidence of six indicators of crime and disorder in each and the percentage of parcel-years with one or more such events (in parentheses)

Cluster	No. of parcel-years	Social disorder	Private conflict	Violence	Guns	Private neglect	Public denig
Violent hubs	1559	1.69 (60.23%)	2.08 (62.47%)	6.58 (96.09%)	0.39 (25.59%)	0.78 (31.24%)	0.44 (23.09%)
Public denigration	3049	0.09 (7.51%)	0.16 (12.30%)	0.20 (12.96%)	0.02 (2.16%)	0.59 (30.63%)	6.59 (100%)
Private neglect	5222	0.07 (6.07%)	0.63 (32.86%)	0.53 (28.63%)	0.05 (4.19%)	4.63 (100%)	0.52 (29.38%)
Guns	9140	0.08 (6.98%)	0.32 (21.51%)	0.54 (30.01%)	1.22 (100%)	0.21 (12.83%)	0.15 (10.53%)
Private conflict	33,842	0.05 (4.61%)	1.33 (100%)	0.32 (20.37%)	0.00 (0.31%)	0.16 (12.06%)	0.14 (10.31%)
No major issues	600,572	0.01 (1.10%)	0.00 (0.00%)	0.05 (4.23%)	0.00 (0.00%)	0.04 (3.41%)	0.07 (5.49%)

Unit of analysis was 653,384 parcel-years (81,673 parcels * 8 years). Each residential parcel was categorized into one of the six profiles of crime and disorder in each year

prevalence and severity, the latter of which we will leverage to describe processes of aggravation and desistance.[2]

- Most parcels in each year exhibited a profile with little or no crime or disorder (91.92% of parcel-years), which clearly is the lowest severity condition.
- About 8% of parcel-years exhibited one of four "single-issue" profiles. These featured concentrations of either private conflict (5.18%), gun-related events (1.4%), private neglect (0.8%), or public denigration (0.47%), but very few instances of other types of issues. When considering severity, we see a division with the two forms of physical disorder being of lesser concern compared to social disorder and violence. Within these, it is not obvious whether private neglect or public denigration is of greater severity, but a concentration of gun-related events is more severe than a concentration of private conflict.
- The least common and most severe profile consisted of parcel-years that experienced a mixture of violence, public social disorder, private conflict, and gun-related events, sometimes accompanied by physical disorder. We refer to these as *violent hubs* (0.24% of parcel-years).

It is worth noting that there are multiple types of residential parcels, which can have implications for the distribution of the profiles of crime and disorder (see SOM for distribution of events and profiles of issues across land use categories). Parcels with fewer units (e.g., single-family homes) were more likely to exhibit the "no major issues" profile than those with more units (e.g., apartments, condo buildings). This could be a function of the greater number of people living in the latter or the demographic characteristics of those living there. Nonetheless, all types of problematic parcels were represented in each category of residential land use, meaning that the typologies were not themselves driven by differences between land uses.

When analyzing profiles of crime and disorder across years, 64.9% exhibited no major issues across the entire timespan. Of the other 35.1%, a striking 7 additional parcels (< 0.01%) exhibited the same problematic profile across all 8 years. Meanwhile, 25.2% of parcels expressed two different profiles and 8.2% exhibited three different profiles over the 8 years. The remaining 1.7% exhibited 4 or more profiles over time. This is preliminary

[2] K-means is a non-deterministic technique that is dependent on the starting point of the process. As a result it can generate various solutions, some of which are "local optima" that fail to fully capture the contours of the data. To address this, we ran the cluster analysis 10 separate times to get a sense of the range of optima identified. Qualitatively, these were nearly identical. There was always a predominant category of parcel-years with no major issues; a smallest category with a mixture of serious issues, or *violent hubs*; and four other categories that featured specialization. This latter group featured slight distinctions across solutions (e.g., the combination of both forms of physical disorder in a single cluster in one solution), but the most consistent composite result was the identification of four clusters specializing in private conflict, public denigration, private neglect, and gun-related events. A second consideration was how liberally "no major issues" was defined by the cluster analysis when a parcel-year had a small number of issues. Across solutions this varied by ~ 30,000 parcel-years (i.e., between 595,000 cases and 625,000 cases). Based on these observations, we prioritized a solution that had cleaner representations of specialization as it made the description of year-to-year transitions more accessible, interpretable, and actionable; and solutions that classified fewer cases as having no major issues in order to minimize the number of potentially meaningful cases that were excluded from the Markov chain analysis. That is what we report here.

evidence that the four phenomena drawn from life-course theory—onset, persistence, aggravation, and desistance—are visible in meaningful amounts in the data.

Four Forms of Stability and Change

We conducted two sets of Markov chains to observe the four phenomena suggested by life-course theory—onset, persistence, aggravation, and desistance. First, we analyzed 2-year chains, quantifying the likelihood that a parcel would transition from one profile of crime and disorder to another in the following year. These results are reported in Table 3, with transitions that occurred more often than expected represented graphically in Fig. 1. Second, we analyzed 3-year chains that examined transition matrices between years two and three, segmented by the parcel's status in the first year. Relevant results from these chains are reported in the text. The full results constitute six separate tables (one for each initial state) that are provided in SOM. The section is organized by the four phenomena, with results from the 2- and 3-year chains combined for each.

To better interpret results we compared them to randomized data. We evaluate the likelihood of a given transition relative to expectations under randomization using odds ratios and significance using t tests based on the standard errors of estimates (see "Methods" section for more detail). Last, based on the K-means cluster analysis, we posited a loose hierarchy for the five types of problematic parcel, ordered by severity. At the top were the violent hubs; next, concentrations of gun-related events and then private conflict; and last concentrations of either form of physical disorder. We use this hierarchy as we interpret the results, especially the pathways for aggravation and desistence. We limit the analysis to the 28,637 parcels (35%) that exhibited any of these five profiles in at least 1 year.

Onset

Onset was not an especially frequent event. Parcels with no major issues in 1 year were modestly more likely to remain that way in the next year (79% actual vs. 77% expected; O.R. = 1.12, $p < 0.001$). Though all forms of onset were lower than expected by chance, some were more likely than others. First, parcels most often experienced onset in the form of many instances of private conflict (14% actual and expected; O.R. = 0.98). At the other end of the spectrum, onset was least likely to manifest in violent hubs and also most underrepresented relative to expectations (0.2% actual vs. 0.7% expected; O.R. = 0.40). Onset in the form of parcels with a concentration of gun-related events, private neglect, and public denigration fell between these extremes.

The 3-year Markov chain models provide mixed evidence as to whether onset is durable. 78% of parcels that experienced onset in year two reverted to having no major issues in the third year. This is in fact the exact same proportion of parcels that were non-problematic across the first 2 years that remained as such into the third year, indicating that those that experienced onset during the time period analyzed were equally likely to have no major issues in the following year as properties that had not experience any issues in the previous 2 years. This proportion varied, however, across types of problematic parcels. Parcels with an onset of incidents of private conflict in year 2 were more likely to have no major issues in year 3 than other parcels with the same profile (81% actual vs. 75% of all parcels with that profile). The same was true for concentrations of gun-related incidents (76% vs. 69%). Parcels where onset took the form of violent hubs or a concentration of public denigration—and, to a lesser extent, a concentration of private neglect—were considerably less

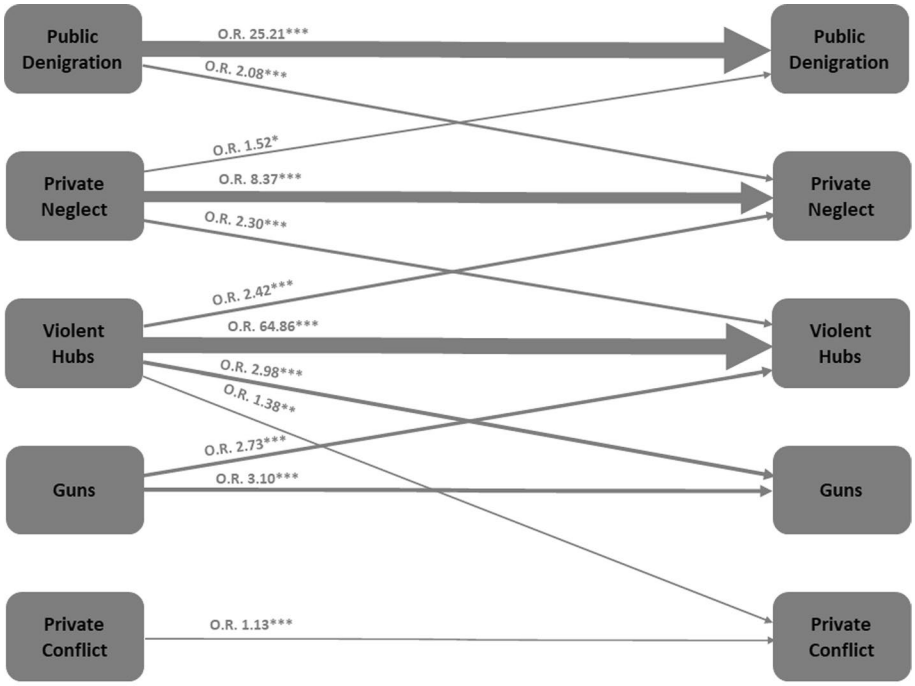
Table 3 Proportion of parcels with each profile of crime and disorder in 1 year (rows) transitioning to each other profile in the following year (columns), including the odds ratio relative to expectations (in parentheses; those more likely than expected in bold)

	Subsequent state					
	No major issues	Private conflict	Guns	Violent hubs	Private neglect	Public denigration
Previous state						
No major issues	**.79 (1.12***)**	.14 (0.98*)	.04 (0.90***)	.002 (0.40***)	.02 (0.76***)	.01 (0.80***)
Private conflict	.76 (0.95)	**.17 (1.13***)**	.04 (0.94)	.01 (1.17)	.02 (1.05)	.01 (0.52***)
Guns	.69 (0.65***)	.14 (1.02)	**.12 (3.10***)**	**.02 (2.73***)**	.02 (1.03)	.01 (0.42***)
Violent hubs	.30 (0.13***)	**.19 (1.38**)**	**.12 (2.98***)**	**.32 (64.86***)**	**.05 (2.42***)**	.02 (1.31)
Private neglect	.61 (0.46***)	.15 (1.02)	.05 (1.16)	**.02 (2.30***)**	**.16 (8.37***)**	**.02 (1.52*)**
Public denigration	.54 (0.32***)	.07 (0.47***)	.02 (0.39***)	.01 (1.59)	**.04 (2.08***)**	**.33 (25.21***)**
Approx. expected value[a]	*.77*	*.14*	*.04*	*.007*	*.02*	*.01*

Analysis is of 200,459 year-to-year transitions at parcels with at least 1 year exhibiting one of the five profiles with major issues (28,637 parcels * 7 2-year chains over an 8-year period). Expectations are established by randomizing the distribution of parcels across states within each year. Odds ratios were calculated as relative to expectation, i.e. $\left(\frac{p_o}{1-p_o}\right)/\left(\frac{p_e}{1-p_e}\right)$. Significance was evaluated through *t* tests comparing the expected and observed values using the standard errors of their estimates generated by the bootstrap procedure for estimating the Markov chains

[a]The expected proportion of parcels exhibiting this profile of crime and disorder, regardless of previous state, if transitions were completely random. These values were estimated by re-running the analyses after randomizing the distribution of parcels across states within each year. We repeated this process 100 times and calculated the mean of each estimate in the transition matrix and the standard errors of these estimates. These are then used as the basis for comparison for the odds ratios reported in each cell in the corresponding column

*$p < .05$; **$p < .01$; ***$p < .001$



* - $p < .05$, ** - $p < .01$, *** - $p < .001$

Fig. 1 Transitions from one profile of crime in disorder to another in the following year that were greater than expected by chance (quantified with odds ratios), based on 2-year Markov chains. *Note*: Graphical representation of the results of the 2-year Markov chains reported in full in Table 3. Lines are proportional to odds ratios with a ceiling at OR = 10 because of outliers. Parcel-years with no major issues were excluded as their transitions to or from all other profiles were not more likely than expected by chance

likely to return to a state of no major issues but still more likely to do so than the average parcel exhibiting that profile of issues (violent hubs: 46% vs. 30%; concentrations of public denigration: 59% vs. 54%; concentrations of private neglect: 71% vs. 61%).

Persistence

All forms of problematic parcels were more likely to persist into the following year, as highlighted in Fig. 1. This was most marked for violent hubs (32% actual persistence vs. 0.7% expected; O.R. = 64.86, $p < 0.001$). The two profiles featuring a concentration of physical disorder followed (public denigration: 33% actual persistence vs. 2% expected; O.R. = 25.21, $p < 0.001$; private neglect: 16% actual persistence vs. 2% expected; O.R. = 8.37, $p < 0.001$). The least likely to persist, though still above expected, were properties with a concentration of guns (12% actual persistence vs. 4% expected; O.R. = 3.10, $p < 0.001$) and private conflict (17% actual persistence vs. 15% expected; O.R. = 1.13, $p < 0.001$).

Persistence was amplified in the 3-year chains: issues that had persisted across 2 years were even more likely to continue into the third year, relative to the expectations of the 2-year chains. In the strongest case, of the 12% of parcels where a concentration of

gun-related events persisted from year 1 to year 2, 27% persisted into the third year (O.R. relative to concentrations of guns = 2.71; O.R. relative to random expectations = 8.66 $p < 0.001$). The next highest such tendency was that for private neglect. Of the 16% of parcels where a concentration of private neglect persisted from years 1 to year 2, 31% saw persistence into year 3 (O.R. relative to concentrations of private neglect = 2.36; O.R. relative to random expectations = 20.32 $p < 0.001$). Notably, the lowest level of persistence in the 3-year models was again for parcels with a concentration of private conflict (25% persistence in the 3rd year vs. 17% in the 2nd year; relative O.R. = 1.89 $p < 0.001$). Overall, this indicates that once a certain type of issue has become established in a place it is increasingly likely to persist.

Aggravation

Of the significant transitions in Table 3 and Fig. 1, the most apparent instance of aggravation was that parcels with a concentration of gun-related events or private neglect tended to transition into violent hubs in the following year (gun-related events: O.R. = 2.73, $p < 0.001$; private neglect: O.R. = 2.30, $p < 0.001$). To put this in practical perspective, only 2% of parcels with a concentration of gun-related events experienced such transitions, but this was relative to 0.6% expected by chance.

Turning to lower-scale aggravations, there were horizontal transitions from concentrations of public denigration to concentrations of private neglect (4% actual vs. 2% expected; O.R. = 2.08, $p < 0.001$), and, to a lesser extent, in the other direction (2% actual vs. 1% expected; O.R. = 1.52, $p < 0.01$). Parcels with concentrations of private conflict or physical disorder did not transition to concentrations of gun-related events any greater than chance.

The 3-year transition matrices offer further insight into how aggravation unfolds. Based on the 2-year results, the only candidate for a three-step pathway was from concentrations of public denigration to concentrations of private neglect to violent hubs. Parcels that experienced the first two steps of this pathway were in fact more likely to become violent hubs in the third year relative to the typical parcel with a concentration of private neglect, but this was non-significant (2.9% actual vs. 0.9% expected; O.R. = 3.41, $p = ns$).

A second question is whether aggravations are durable. Parcels with concentrations of private neglect or gun-related events that transitioned to violent hubs remained that way less often than parcels that had been violent hubs in year 1 (23% for private neglect and 18% for gun-related events vs. 50% for violent hubs in year 1), though still more likely to persist than expected by chance (O.R.s = 42.37 and 31.13 relative to expectations, respectively, p values < 0.001). As above, it appears that the longer a place exhibits a profile of crime or disorder, the more likely it is to continue to do so; contrastingly, parcels without that history do not exhibit the same level of persistence.

Desistance

Desistance may take one of two forms: cessation of issues or de-escalation to less severe issues. As hypothesized, cessation was uncommon relative to chance. Parcels with a concentration of private conflict were alone in being neither more nor less likely than chance to transition to having no major issues in the following year (76% actual vs. 77% expected; O.R. = 0.96, p value = ns). All the rest were markedly less likely than chance to experience cessation (O.R.s = 0.13–0.65, all p values < 0.001). This suggests that where desistance

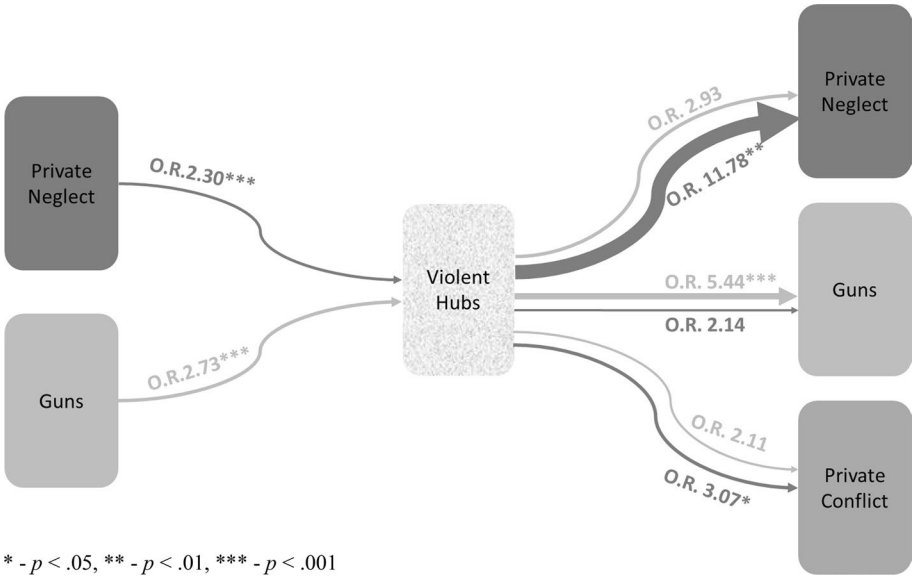


Fig. 2 Pathways of aggravation to violent hubs and their mirror-image de-escalations, with likelihoods relevant to expectations by chance (quantified with odds ratios), based on 3-year Markov chains. Pathways are differentiated by their origination in concentrations of private neglect (dark gray) and gun-related events (light gray). *Note*: Graphical representation of results from the three-year Markov chains reported in full in Appendix C. Lines are proportional to odds ratios

is occurring, especially for violent hubs, there is a more gradual transition to less severe issues.

As illustrated in Fig. 2, we see that violent hubs tend to step down to having a concentration of gun-related events (12% actual vs. 4.2% expected; O.R. = 2.98, p value < 0.001) or private neglect (5.4% actual vs. 2.3% expected; O.R. = 2.42, p value < 0.001). This is notable being that these profiles of crime and disorder were the ones that tended to escalate into violent hubs. Further, the specific history of escalation was predictive of the pathway for de-escalation. Three-year chains revealed that each violent hub was more likely to step down to the profile of issues with which it started. Parcels with previous concentrations of gun-related events were more likely to revert to the same than to a concentration of private neglect (return to concentration of gun-related events: 24%, O.R. = 5.44, p value < 0.001; concentration of private neglect: 8%, O.R. = 2.93, p value = *ns*), and vice versa (return to concentration of private neglect: 15%, O.R. = 11.78, p value < 0.01; concentration of gun-related events: 12%, O.R. = 2.13, p value = *ns*). This shows that aggravation to and de-escalation from violent hubs tend to be mirror-images of each other.

Violent hubs also stepped down to concentrations of private conflict more often than chance (19% actual vs. 15% expected; O.R. = 1.38, p value < 0.01). This was unexpected given that concentrations of private conflict showed no consistent pathway to violent hubs through escalation. Interestingly, in the last stage of the 3-year chains, this transition was overrepresented for violent hubs that in year 1 had had concentrations of private neglect (27% vs. 14% expected, O.R. = 3.07, p value < 0.05), suggesting an alternate pathway to desistance that does not mirror the initial process of aggravation.

The partial de-escalations from violent hubs to other profiles of crime and disorder were not reliable pathways to cessation of issues, however. For instance, when a violent hub

transitioned to having only a concentration of gun-related events in the second year, its third-year states were almost evenly divided between becoming a violent hub (25%), persisting with a concentration of gun-related events (24%), and having no major issues (31%). These values were markedly different from all parcels with a concentration of gun-related events, the majority of which saw cessation in year 2 (69%). A similar story was observable for those whose severity de-escalated to concentrations of private neglect: 14% reverted to being violent hubs (vs. 1.6% of all parcels with concentrations of private neglect) and 23% had no major issues in the third year (vs. 61% overall). Violent hubs that stepped down to concentrations of private conflict also were substantially more vulnerable to re-escalation to violent hubs (12% vs. 0.8%) than similar parcels lacking this history. That said, with 42% of these parcels transitioning to having no major issues in the following year (vs. 76% overall), they represented a more consistent pathway to complete cessation than the others.

Neighborhood Context

To understand how the four phenomena of interest differ by neighborhood context, we replicated the analyses splitting parcels by whether they were in a census tract with above or below the mean level of crime and disorder (quantified as the rate of events across all categories per 1000 residents; 17,648 and 10,989 parcels, respectively). For brevity, we focus here on the main findings in the 2-year chains (see Table 4), walking through the four transitions of the life course in order. We use two types of comparisons to illustrate differences between neighborhoods. First, we present traditional comparisons of the proportion of parcels that experience each transition in each of the two types of neighborhoods. However, these do not account for the different expectations owing to the local prevalence of crime and disorder. For this reason, we also compare the relative magnitude of the difference each had with its locally expected outcomes.[3,4]

Onset was more common in neighborhoods with above-average crime and disorder, as might be expected. Parcels in those neighborhoods with no issues in 1 year were more likely to exhibit concentrations of private conflict (15% vs. 13%), private neglect (1.8% vs. 1.5%), and gun-related events (4.8% vs. 2.2%) in the following year than their counterparts in neighborhoods with below-average crime and disorder. Interestingly, concentrations of public denigration were more likely to appear in neighborhoods with below-average crime and disorder

[3] This was accomplished in three steps. We first calculated the t value for the difference between the observed and expected likelihood of a given cell in the probability transition matrix separately for neighborhoods with above- and below-average crime. We then translated these t values to Cohen's d, a standardized measure of magnitude, using the equation $2 * \frac{t}{\sqrt{n-2}}$ where n was the number of parcels who could have experienced that transition (i.e., for a_{ij}, n=# of parcels with initial state of i). We also calculated the sampling variance (v) for each d value as $v = \frac{1}{n_1} + \frac{1}{n_2} + \frac{d^2}{2*(n_1+n_2)}$. These values then permitted a traditional z-score calculation of $z = \frac{d_1-d_2}{\sqrt{v_1+v_2}}$ that evaluated whether the magnitude of difference from expectations was different between the two contexts.,

[4] The reader may note that the exclusion of parcels that never experienced major issues across the study period will remove more parcels from neighborhoods with below-average crime and disorder than from those with above-average crime and disorder. Because the transition calculations in the Markov chain are contingent on the starting transition, this is only consequential for transitions that begin at a point of no major issues. In the analysis here, this is limited to examinations of onset as the other three phenomena operate from the starting point of experiencing major issues. In light of this, comparing with local expectations clarifies the interpretations by accounting for the proportion of parcel-years in the "no major issues" category in the remaining sample.

Table 4 Proportion of parcels with each profile of crime and disorder in 1 year (rows) transitioning to each other profile in the following year (columns), including the odds ratio relative to expectations (in parentheses; those more likely than expected in bold), compared between neighborhoods with above- and below-average crime

	No major issues	Private conflict	Guns	Violent hubs	Private neglect	Public denigration
Above-average crime neighborhoods						
No major issues	**.78 (1.15***)**	.15 (0.95***)	.05 (0.88***)	.003 (0.39***)	.02 (0.73***)	.005 (0.82***)
Private conflict	.72 (0.87**)	**.19 (1.21***)**	.05 (0.94)	.009 (1.20)	.03 (1.10)	.004 (0.69**)
Guns	.67 (0.64***)	.15 (1.01)	**.14 (2.75***)**	**.02 (2.35***)**	.02 (0.92)	.00 (0.61*)
Violent hubs	.29 (0.14***)	**.20 (1.35*)**	**.14 (2.46***)**	**.30 (60.39***)**	**.06 (2.52***)**	.01 (2.12)
Private neglect	.57 (0.44***)	.16 (1.04)	.06 (1.14)	**.02 (2.17***)**	**.18 (8.36***)**	**.01 (1.89*)**
Public denigration	.55 (0.38***)	.10 (0.67**)	.04 (0.63)	.02 (2.09)	**.07 (2.82***)**	**.23 (34.10***)**
Approx. expected value[a]	*.75*	*.15*	*.06*	*.01*	*.03*	*.01*
Below-average crime neighborhoods						
No major issues	.81 (1.06)	.13 (1.03)	.02 (0.99)	.003 (0.44***)	.02 (0.86***)	.02 (0.76***)
Private conflict	**.82 (1.19*)**	.12 (0.92)	.02 (0.80*)	.007 (1.09)	.02 (0.89)	.01 (0.51***)
Guns	.79 (0.88)	.11 (0.85)	**.06 (3.00***)**	**.02 (2.68**)**	.02 (0.98)	.02 (0.65)
Violent hubs	.33 (0.12***)	**.18 (1.51*)**	**.08 (3.57**)**	**.36 (112.14***)**	.04 (2.00)	.02 (0.82)
Private neglect	.69 (0.58**)	.12 (0.87)	.02 (0.80)	**.01 (2.88*)**	**.12 (7.76***)**	.04 (1.31)
Public denigration	.53 (0.29***)	.05 (0.42***)	.01 (0.39**)	.006 (1.09)	**.03 (1.66*)**	**.37 (15.24***)**
Approx. expected value[a]	*.80*	*.13*	*.02*	*.01*	*.02*	*.03*

Analysis is of 123,536 year-to-year transitions at parcels with at least 1 year exhibiting one of the five profiles with major issues (top panel; 17,648 parcels * 7 2-year chains over an 8-year period) and 76,923 year-to-year transitions (bottom panel; 10,989 parcels * 7 2-year chains over an 8-year period). Expected outcomes were established by randomizing the distribution of parcels across states within each year. Odds ratios were calculated as relative to expectation, i.e. $\left(\frac{p_o}{1-p_o}\right)/\left(\frac{p_e}{1-p_e}\right)$. Significance was evaluated through *t* tests comparing the expected and observed values using the standard errors of their estimates generated by the bootstrap procedure for estimating the Markov chains

[a]The expected proportion of parcels exhibiting this profile of crime and disorder, regardless of previous state, if transitions were completely random. These values were estimated by re-running the analyses after randomizing the distribution of parcels across states within each year. We repeated this process 100 times and calculated the mean of each estimate in the transition matrix and the standard errors of these estimates. These are then used as the basis for comparison for the odds ratios reported in each cell in the corresponding column

*$p < .05$; **$p < .01$; ***$p < .001$

(2.1% vs. 0.5%). There was no difference in the likelihood of violent hubs emerging at parcels with no major issues in the previous year between the two types of neighborhoods (both 0.3%). These results shift, though, once we account for the local prevalence of each profile of crime and disorder. In fact, onset was more common in neighborhoods with below-average crime for all types *except* concentrations of public denigration relative to the prevalence of a given profile in the neighborhood (t values = 3.41–4.96, all p values < 0.001; also, compare corresponding odds ratios in the top and bottom panels of Table 4). This is likely due to the analytic strategy of limiting to parcels that exhibited a problematic profile in at least 1 year, which would overemphasize parcels that had years both with and without major issues in neighborhoods with below-average crime.

Persistence was stronger in neighborhoods with above-average crime and disorder for multiple profiles of crime and disorder: concentrations of private conflict (19% of parcels persisting vs. 12% in below-average crime neighborhoods), private neglect (18% vs. 12%), and gun-related events (14% vs. 5.5%). Notably, these differences remained true when taking into account the elevated prevalence of the same profiles of issues in the neighborhood (t values = 2.10–7.39, all p values < 0.05; private conflict, $p < 0.001$).

Aggravation from concentrations of private neglect and gun-related events to violent hubs was present in neighborhoods with both above- and below-average crime and disorder. Though these tendencies were numerically greater in neighborhoods with above-average crime and disorder, neither was significant (concentrations of gun-related events: 1.8% vs. 1.7%; $t = 0.97$, p value = *ns;* concentrations of private neglect: 1.7% vs. 1.4%; $t = -0.46$, p value = *ns*). Horizontal shifts from concentrations of public denigration to concentrations of private neglect and vice versa did differ by type of neighborhood, but this was driven by concentrations of private neglect being more common in neighborhoods with above-average crime and concentrations of public denigration being more common in neighborhoods with below-average crime. Relative to local expectations, there was a modest tendency for concentrations of private neglect to transition to public denigration in neighborhoods with above-average crime and disorder ($t = 2.06$, $p < 0.05$).

Last, *desistance* tended toward different pathways depending on whether a parcel was in a neighborhood with above- or below-average crime and disorder. The partial step-downs from violent hubs to concentrations of private neglect or gun-related events were somewhat more common in neighborhoods with above-average crime, but these differences were non-significant relative to expectations (concentrations of private neglect: 6.2% vs. 3.8%; concentrations of gun-related events: 13% vs. 7.6%; $t = 1.05, -1.45$, respectively, p values = *ns*). In contrast, cessation was much more frequent in neighborhoods with below-average crime. For example, 72% of parcels with concentrations of private conflict in neighborhoods with above-average crime and disorder had no major issues in the following year; meanwhile the same was true for 82% of such parcels in neighborhoods with below-average crime and disorder ($t = 5.06$, $p < 0.001$, for difference relative to local expected proportions). The same values were 69% and 57% for parcels with concentrations of private neglect ($t = 4.59$, $p < 0.001$), and 79% and 67% for parcels with concentrations of gun-related events ($t = 4.69$, $p < 0.001$).

Discussion

Our prospective analysis of crime and disorder at residential parcels in Boston, MA illustrated four phenomena of stability and change in crime and disorder: onset, persistence, aggravation, and desistance. All four components were readily apparent in the data, moving

beyond previous research that has primarily concentrated on persistence at places (Weisburd et al. 2004, 2009, 2012; O'Brien and Winship 2017; Braga et al. 2010, 2011; Trickett et al. 1995; Johnson et al. 2007; Farrell and Pease 2001). Thanks to the use of Markov chains to track shifts between profiles of crime and disorder, it was possible to identify events that were more likely than chance but that would have been overwhelmed by more common events (e.g., persistence) or are too precise to define and observe through other techniques. The results lay the groundwork for further exposition of trends in crime and disorder at problematic parcels and associated interventions. Before we elaborate on these opportunities, we first summarize the main characteristics of each of the four components of the life course as observed here.

Onset was less common than might be expected by chance, which was anticipated given the extended body of work showing that places tend to maintain a characteristic level of crime or disorder, or lack thereof, over many years (Weisburd et al. 2004, 2009, 2012; Braga et al. 2010, 2011). Onset at a parcel was most likely to manifest in the form of private conflict and least likely to manifest as a violent hub. This is consistent with the hypothesis that the emergence of problematic properties will be characterized by a less severe, less varied set of issues, though onset as physical disorder, the least severe type of issue, was not more common. Correspondingly, *persistence* was very common, especially for more serious profiles of crime and disorder. It also exhibited momentum, becoming more durable as a certain type of crime or disorder had been present at that place for longer.

Aggravation and *desistance* largely proved to be mirror images of each other. Concentrations of gun-related events and private neglect were prone to escalating into violent hubs. Meanwhile, de-escalation at violent hubs tended to follow the same steps in reverse, as parcels that had previously exhibited concentrations of gun-related events or private neglect were more likely to eventually revert to the same original profile of crime and disorder. There was also an alternate de-escalation pathway from violent hubs to concentrations of private conflict. Full cessation was uncommon for places that had at one time been violent hubs, however, whereas it was approximately equal to chance for concentrations of gun-related events and private conflict that did not have such a history. This implies that places whose routine activities once generated high-severity mixes of crime and disorder have difficulty achieving the complete elimination of issues, strongly supporting the view that desistance entails a gradual de-escalation.

We found evidence for the hypothesis that neighborhood context helps shape the shifts in issues at parcels, though only for persistence and desistance. Parcels in neighborhoods with above-average crime and disorder were more likely to experience persistence, which is consistent with numerous previous studies on the way high-crime contexts reinforce both repeat offending and victimization (Trickett et al. 1995; Johnson et al. 1997; O'Brien and Winship 2017). Likewise, desistance was less common in neighborhoods with above-average crime, though in a nuanced manner. Gradual de-escalation from violent hubs was reasonably common in all types of neighborhoods, but full cessation was far more likely in neighborhoods with below-average crime and disorder. This suggests that a high-crime context might hinder complete cessation.

In the remainder of this section we forward three directions for future research and practice on problematic parcels: the interplay of stability and change; the role of different forms of disorder; and desistance and interventions. It is also possible that some of these insights might be extended to places writ large, including street segments. It is important to note, however, some limitations of the study, the most apparent arising from our longitudinal data. Though 8 years is a substantial timespan, most parcels in Boston, MA existed for decades before the study period and will likely continue to do so for decades. Thus, as we have

noted, any claims to onset and desistance are limited to the more modest definition of the emergence or disappearance of major issues from 1 year to the next. The 3-year Markov chains make these interpretations somewhat stronger, and in fact provided evidence that these shifts were more durable than chance. Nonetheless, it is important to recognize that onset and desistance events in this study very well could have been followed by reversions to the earlier state at a later point in the future.

Additionally, there are multiple areas that require replication. First, we have conducted the analysis on a single city, Boston, MA. It would be important to do the same in cities in other parts of the United States and the world, especially those with different structures (e.g., twentieth century cities with a more spaced-out, suburban design) and demographics. There has been some evidence that persistence in crime concentrations is less stable in some cities, suggesting that the exact dynamics observed might be different as well (Hipp and Kim 2017). Also, we have explicitly conducted this study on residential parcels, which calls for replications on other types of places, including non-residential problematic parcels as well as hotspot streets. Second, the records used here are reported mainly by constituents, meaning they are potentially an incomplete representation of crime and disorder at places in the city. It is well established that neighborhoods can have different propensities for reporting issues (Klinger and Bridges 1997; O'Brien et al. 2015), and it would be best to replicate this work with other measures of crime, like crime reports or victimization surveys, which feature different forms of bias. Third, when examining how context influenced the trajectories of problematic parcels, we selected neighborhoods, approximated by census tracts, as the geographic scale of interest. This was in part in response to an ongoing debate regarding the complementary roles of community and place in the literature, but there may be other scales of interest. In particular, future research might consider the role of the street segment, as hotspots might reinforce the longitudinal dynamics of problematic properties in ways absent at non-hotspots and distinct from the role of the broader neighborhood. Taken together, these opportunities for replication suggest that some of the precise results observed here may differ by locale and application, but the overall story they tell should prove useful in how a research agenda on the life course of problematic places develops.

Stability and Change

Existing work on the criminal careers of places has been dominated by two main lines of inquiry: one that has highlighted the stability of crime across time at street segments (e.g., Weisburd et al. 2004, 2009, 2012; Braga et al. 2010, 2011) and properties (e.g., O'Brien and Winship 2017; Trickett et al. 1995; Johnson et al. 2007; Farrell and Pease 2001); and a second that has tested if and how disorder can encourage or escalate into more serious issues, a form of aggravation posited by multiple theories (Wilson and Kelling 1982; Branas et al. 2016; O'Brien and Sampson 2015). Our analysis observed substantial evidence of both stability and change in crime and disorder at parcels, extending each of these two lines of inquiry. Unsurprisingly, there was much stability over the 8 years of data. 65% of parcels never exhibited meaningful amounts of crime or disorder. Among the other 35%, persistence was the most common tendency from year to year, *but* almost every single parcel exhibited at least one shift in its profile of issues, constituting substantial amounts of onset, aggravation, and desistence. There are three ways of interpreting this change, and each may have its place.

The first interpretation is that year-to-year changes might be the expression of within-place variability but without any true shifts in the underlying routine activities responsible

for crime or disorder. As such, "change" is merely measurement error hovering around a characteristic level or mix of crime and disorder, something that has also been observed with individual offenders (sometimes referred to as intermittence; Osgood and Schreck 2007; Piquero 2004). This could explain some of the results here: persistence was lower in parcels that recently experienced onset; when escalation to a violent hub was followed by de-escalation, the parcel often returned to the profile of crime and disorder it had experienced previously; de-escalation was often followed by re-aggravation. The practical implication is that many year-to-year changes are ephemeral fluctuations wherein the place will likely revert to the previous state in the following year.

Nonetheless, within-place variation need not always be dismissed as mere measurement error. For instance, individuals are more likely to offend in various ways when experiencing stressful conditions than at other times (Slocum et al. 2005). Likewise, repeat victimizations of the same individual or property, as well as "near repeats" occurring close by, tend to occur in rapid temporal succession (Bowers and Johnson 2005; Bernasco 2008). Whereas a focus on the outcome alone might look like a statistical fluctuation, such phenomena indicate that the timing and influence of underlying contextual factors are still meaningful. The same reasoning might be applied to a problematic parcel experiencing an escalation of crime or disorder. The escalation might be associated with short-term shifts in the underlying routine activities of the place, and the speed and extent to which they re-equilibrate will have major implications for whether the place continues to experience aggravation. Similar considerations would apply to how durable desistance is in the case of a de-escalation. It may be that well-targeted interventions could capitalize on these incremental shifts in local dynamics that might otherwise end up being ephemeral fluctuations.

Third, it is possible that some changes are not natural fluctuations but reflect a fundamental shift in the dynamics of a place. The most dramatic example was the 30% of violent hubs that transitioned to having no issues in the following year. Though such parcels were relatively uncommon, 81% of them remained in the no issues group the following year. This appears to be suggestive of complete cessation, even if the limited timespan of the data makes it difficult to confirm as much. These sorts of transformations likely arise from a full reorientation of local dynamics. This would be analogous to the concept in life course theory of "turning points" (Sampson and Laub 1993; Laub and Sampson 2001). Although turning points are pegged to life transitions that are often part of the developmental process, like marriage, the underlying idea may still be relevant to places. Turning points transform the social context of the individual, fundamentally altering their proclivity for offending. One analogous explanation for places comes from Eck and colleagues' work on place management (Eck 2018; Eck and Weisburd 1995; Madensen and Eck 2013). If place management is a critical ingredient to the prevention of crime and disorder, then we might anticipate changes in ownership or other critical personnel at a place (e.g., rental management companies) could dramatically change social dynamics and, in turn, the frequency and mixture of crime and disorder. There might also be cases in which changes might arise from turnover in residents, be they tenants or homeowners. Across these and other examples, the key is that a turning point in the social context has altered a place's underlying propensity for crime and disorder.

Roles of Different Types of Disorder

There are numerous theories for how disorder can lead to crime, including: broken windows theory, which posits that public disorder will encourage more serious forms of

delinquency (Wilson and Kelling 1982); social escalation theory, which argues that private conflicts between household members or neighbors can give rise to interpersonal violence (O'Brien and Sampson 2015); and ecological advantages theory, which argues that certain forms of disorder can facilitate crime (e.g., abandoned buildings as a hiding place for contraband; Branas et al 2016; St. Jean 2007). How the results here add to these perspectives is nuanced.

First, we saw a partial division between physical disorder and social disorder. Only parcels with concentrations of private neglect had the tendency to crossover to social disorder, sometimes being part of the escalation to or de-escalation from violent hubs. Meanwhile, concentrations of public denigration had no such tendencies. This is most consistent with SET and ecological advantages. Transitions from private neglect to social disorder and violence could reflect social escalation in the personal challenges among place managers, residents, or both. It might also be that these forms of disorder are creating ecological advantages for certain types of crime.

The evidence for SET did not continue, however, as concentrations of private conflict were distinctly less likely to indicate further issues to come. It was the least persistent profile of crime or disorder, had no clear pathways for aggravation to more serious social issues (e.g., violence), and was the most likely to transition to full cessation. It was also the profile of crime and disorder most often observed as onset. This all suggests that, while concentrations of private conflict can of course persist across time, they have the potential to be temporary challenges at otherwise non-problematic parcels and do not necessarily portend aggravation. Likewise, the lack of aggravation for parcels with concentrations of public denigration and the overall unimportance of public social disorder provide at best no new support for BWT, and potentially add to the research calling its basic premise into question (O'Brien et al. 2018; Sampson and Raudenbush 1999; Weisburd et al. 2015a, b). In each of these cases, however, it is important to keep in mind the distinct analytic strategy used here and its implications. Whereas past studies on these theories have included events at all places, we limited to places that expressed a distinctive profile of crime and disorder; a non-trivial proportion of places in each year had a small amount of crime or disorder that was insufficient to place it in one of these profiles, thus excluding them from analysis. Further, SET and BWT do not necessarily predict wholesale transitions between types of crime and disorder, and some phenomena that would be consistent with them—for example, a parcel with a large amount of disorder experiencing one or two events of violence in the following year—would not have been captured here.

Interventions and Desistance

Possibly the most practically informative findings from the results regarded desistance. Problem properties task forces and similar initiatives pursue complete cessation of crime and disorder. Most often the interventions are rooted in "nuisance laws," which enable municipalities to take control of properties that are havens of illicit economic activity, like drug dealing and prostitution (Way et al. 2013; LISC 2019; Boston 2011). For example, once the City of Boston designates a problem property, it charges the owner for every subsequent police or inspectional visit, thereby incentivizing the elimination of all issues and disturbances. The results here, however, suggest that the true process of desistance is gradual, paralleling the observation in life course research that cessation and desistence are not equivalent—instead, the former is the hoped-for endpoint of a gradual de-escalation from a peak of offending (Kazemanian 2007).

Just as Ward et al. (1997) have argued that understanding this process will enable the design of more effective interventions for offenders, problem properties task forces might adopt new techniques that better facilitate de-escalation rather than targeting cessation outright. One solution could be for task forces to adopt distinct short- and long-term goals for the most problematic places. It might be that, in the absence of any major turning points in the residents or owners of a place, the immediate cessation of all issues is overly ambitious. Instead, the routine activities and social dynamics of a stable set of actors will need to be adjusted. Being that it would be difficult to do so overnight, the more reasonable objective would be to gradually lessen severity and frequency. Cessation would then be a long-term goal made possible by protracted efforts. There is also the consideration of the exacerbating or reinforcing role of the neighborhood, wherein greater patience will be needed for parcels experiencing de-escalation in high-crime neighborhoods.

One crucial issue we do not address here and that requires further research is that of the quantitative lessening of issues. We have exclusively examined the mix of types of issues at a parcel, setting aside the frequency of those events. We have not yet examined whether violent hubs with fewer total events or fewer high-severity events (e.g., those entailing violence) are more likely to experience de-escalation, or if there might be gradual decreases in the frequency of events that mirror the gradual de-escalation in types of events that we concentrate on here. Insights on these processes would be further informative to designing intervention strategies that capitalize on the ways in which desistance naturally proceeds.

Conclusion

We have empirically illustrated four phenomena reflecting trends in crime and disorder at problematic parcels: onset, persistence, aggravation, and desistance. Whereas other research has highlighted the predominance of persistence and, to a lesser extent, patterns of aggravation from disorder to crime, the strategies taken here offered a window into all four processes. The result is a richer vantage point on stability and change in disorder and crime at places, with especially actionable insights on desistance as a nuanced, gradual process of de-escalation. The results also added to a growing literature on the interplay between places and communities in driving trajectories of crime. These results are immediately meaningful in understanding how problematic parcels emerge and evolve over time, and they also set the stage for further work, including extensions to other types of "places" (e.g., commercial institutions, hotspot streets); the further articulation of when and how these phenomena unfold; and applications that translate the results into effective interventions.

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