Landscape and Urban Planning 221 (2022) 104359

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Shifting landscape suitability for cocaine trafficking through Central America in response to counterdrug interdiction

Nicholas R. Magliocca [a,*], Diana S. Summers [b,1], Kevin M. Curtin [a], Kendra McSweeney [c], Ashleigh N. Price [a]

[a] Department of Geography, University of Alabama, United States
[b] Homeland Security Investigations, Department of Homeland Security, United States
[c] Department of Geography, The Ohio State University, United States

HIGHLIGHTS

- Landscape suitability for cocaine trafficking across Central America was analyzed.
- Landscape suitability changed over space and time with law enforcement pressure.
- Lower population density and international border areas were consistently suitable.
- Trafficking disproportionately increased through indigenous territories after interdiction elsewhere.
- Logistical rather than productive landscape suitability important to illicit economic actors.

ARTICLE INFO

Keywords:
Crime geography
Criminal networks
Routine activity theory
Suitability mapping
Spatio-temporal modeling

ABSTRACT

Cocaine traffickers, or 'narco-traffickers', successfully exploit the heterogeneous landscapes of Central America for transnational smuggling. Narco-traffickers successfully adapt to disruptions from counterdrug interdiction efforts by spatially adjusting smuggling routes to evade detection, and by doing so bring collateral damages, such as deforestation, corruption, and violence, to new areas. This study is novel for its integration of landscape suitability analysis with criminological theory to understand the locations of these spatial adaptations by narco-traffickers as intentional, logical, and predictable choices based on the socio-environmental characteristics of Central America's landscapes. Multi-level, mixed effects negative binomial regression models predict the suitability of landscapes for cocaine trafficking across 17 *departamentos* (the unit of analysis) in Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama from 2007 to 2018. Informed by long-term research in the region, independent variables included proximity to roads, country borders, and international ports, indigenous territories, population density, and protected areas. The year of peak interdiction (measured by kg of cocaine seized) in each *departamento* was used to analyze spatial shifts in landscape suitability before and after maximum counterdrug interdiction pressure. We find that areas with lower population density and closer proximity to international borders became more suitable following peak interdiction—i.e, they are more likely to be sought out by traffickers seeking to avoid further disruptions from counternarcotic efforts. Additionally, indigenous territories were disproportionately exploited as cocaine trafficking routes following significant interdiction activities by law enforcement. While interdiction may reduce the suitability of targeted locations, it can also unintentionally increase the attractiveness of other locations. Our study pushes criminological theory through its application to a unique space/time context, and it advances land system science by considering landscape suitability for logistical rather than productive uses. Policy implications are clear. Since interdiction resources are limited relative to the overall amount of trafficking activity, knowing which landscape features are viewed as

* Corresponding author.
E-mail address: nrmagliocca@ua.edu (N.R. Magliocca).

[1] This research was prepared independently of Homeland Security Investigations (HSI). The views expressed in this article do not necessarily represent the views of HSI, the Department of Homeland Security (DHS), or the United States.

https://doi.org/10.1016/j.landurbplan.2022.104359
Received 29 March 2021; Received in revised form 12 January 2022; Accepted 15 January 2022

suitable by traffickers can in the short-term guide interdiction deployment strategies, and in the longer term build strategies to mitigate associated harms from trafficking where they are most likely.

1. Introduction

Despite more than 40 years of U.S.-led counternarcotic efforts in the Western Hemisphere, northbound cocaine movements through the 'transit zone' – Central American countries, their coastlines, and surrounding Caribbean and eastern Pacific waters – continue to rise (ONDCP, 2018), including an unprecedented 2,976 metric tons that moved into the region in 2016[2]. Notwithstanding numerous related U.S. national security concerns (e.g., Kelly, 2016), U.S. counterdrug interdiction efforts to stem the flow of cocaine into the U.S. have rarely intercepted more than 10% of the known flow through this area (Faller, 2019; OIG, 2019). Moreover, the amount of cocaine that has been seized by law enforcement officials has not had significant or sustained impact on cocaine prices in the U.S. nor negatively impacted traffickers' profits (McSweeney, 2020; Reuter, Pollack, & Pardo, 2016). A well-documented explanation for the ineffectiveness of interdiction is the adaptability of drug trafficking organizations (DTOs), which often respond to disruptions by adjusting cocaine flow volumes along existing routes and/or exploiting new route locations (Magliocca et al., 2019; Magliocca et al., in press; McSweeney, 2020; Reuter, Pollack, & Pardo, 2016). Further, the emergence of cocaine trafficking, or 'narco-trafficking', activities in specific areas has been linked to localized corruption, violence, environmental degradation, and dispossession of land and/or livelihoods of local communities (McSweeney et al., 2014, 2017; Dávila et al., in review; Devine et al., 2018; Gore et al., 2019; Sesnie et al., 2017; Tellman et al., 2020a). Understanding the characteristics of landscapes that appeal to narco-trafficking operations as they adapt to counterdrug interdiction pressures is key to anticipating the spread and intensity of their associated social and environmental harms.

This study draws greater attention to the attributes of landscapes that attract traffickers, and to the ways in which traffickers' decisions to develop new sites of transshipment are shaped by the level of law enforcement (LE) pressure that they have experienced. Beyond the well-established fact that criminals are spatially adaptive in response to LE (Guerette & Bowers, 2009), relatively few studies have explored: a) a threshold of spatially targeted LE activity most likely to catalyze criminals' spatial re-orientation, b) the attributes of landscapes to which criminals are most drawn to resume their activities following displacement, and c) how these dynamics play out across the heterogeneous landscapes of an entire region (rather than at the neighborhood scale) over a long period of time (a decade). This study explores these spatial dynamics through a novel landscape-level application of a criminological theory - routine activities theory. We focus particularly on examining the physical spaces that narco-trafficking networks are attracted to between and within the countries of Central America. Specifically, we explore how some particular landscapes become more or less suitable to traffickers – i.e., "land suitability" – following the experience of sustained, geographically targeted interdiction efforts over a ten-year period.

In the context of interdiction efforts in the Western Hemisphere, the insights presented here should allow researchers, policymakers, and others to better understand the inherent predictability of traffickers' spatial adaptations. Rather than considering those spatial adaptations—and the violence, corruption, and socio-ecological impacts they provoke—as 'unintended,' we suggest that after almost a half-century of this dynamic we should understand them as intentional, logical, and predictable with respect to the type of physical environments most favored.

[2] Source: Consolidated Counterdrug Database (CCDB)

2. Background

2.1. Theoretical framework

Routine activity theory is a spatial–temporal criminological theory that examines the dynamics of place and moments in everyday life that can lead to criminal victimization (Eck & Weisburd, 1995). Developed in the late 1970s, routine activity theory suggested that a potential offender (with both the inclination and ability to commit crime) will engage in the criminal act at the convergence of an object or person seen as valuable to the offender and insufficient "guardianship" capable of preventing or deterring the crime (Cohen & Felson, 1979; Felson, 1995). This theory was originally applied at the micro- and *meso*-levels, examining the environmental design of a particular neighborhood in relation to victimization rates (for instance) (Rice & Smith, 2002). In other words, routine activity theory originally studied what people were doing in their daily lives that were putting themselves or their property at risk, and how "capable guardianship" might better protect them (Farrell, 1998).

However, research on routine activity theory since the early 1980s has expanded the theory's application to the macro-level and agent-based work (Groff, 2007, 2008), studying a broad range of crimes and situations, including those that challenge the traditional notions of space and time (e.g., Leukfeldt & Yar, 2016; Messner & Tardiff, 1985; Rice & Smith, 2002). These studies have applied routine activity theory to study aggregated criminal phenomena in national and international comparative contexts, such as examining large scale drug trafficking efforts, criminal networks (e.g., Duxbury & Haynie, 2019), transnational cybercrimes (Holt, Burruss, & Bossler, 2016), and how trucking fleet size, comparatively lower prices for heroin and cocaine, and "routine economic and social activities" may impact DTOs' movements through the Netherlands (Farrell, 1998: 24).

Prior research has further clarified the concepts of "suitable targets" and "capable guardians," acknowledging that the former extends beyond objects with monetary value (Bossler & Holt, 2009). A suitable target in this sense, then, is anything that the rationally motivated offender finds desirable and is accompanied by a lack of guardianship, thus creating criminal opportunity. Guardianship, then, is multifaceted and can refer to environmental target-hardening approaches, such as security systems, checkpoints, and physical or natural barriers (e.g., mountainous terrain) (e.g., Leukfeldt & Yar, 2016). The concept of guardianship also encompasses individuals or groups and actions by these groups (e.g., seizures of drugs by law enforcement, the presence of peers, social organizations, targeted enforcement) who may dissuade criminals or otherwise prevent the criminal behavior (Braga, 2001; Duxbury & Haynie, 2019; Farrell, 1998; Holt, Burruss, & Bossler, 2016. In this study, guardianship is conceptualized using the latter framework; that is, the authors considered how the actions of law enforcement, operationalized as the amount of cocaine seized by multiple agencies in the target region, impacted the physical routes taken by cocaine traffickers over time. Guardianship, then, is represented by the amount of cocaine removed by capable guardians in the Central American countries included in this study, thus negatively impacting (i.e., theoretically deterring or dissuading) trafficking operations in areas of seizures.

When conceptualizing spatial vulnerability, the elements that represent the suitability of targets and capable guardianship (that might prevent or deter crime) are particular to the context in which the crime occurred (Felson & Eckert, 2015). For some criminologists, this has led to a focus on (urban) land use and efforts to secure and design space to "alter the environment in ways that keep potential offenders away from suitable targets" (Tilley et al., 2015: 59). Other research avenues have

investigated locations that might facilitate crime, such as bars (e.g., Roncek & Maier, 1991; Roncek & Pravatiner, 1989) and schools (e.g., LaGrange, 1999). Scholars have also studied nonresidential land use (e.g., Sampson & Raudenbush, 1999) and employed indices of land use data to explore criminal propensity and propinquity (e.g., McCord et al., 2007; Stucky & Ottensmann, 2009). In addition to the function of the land itself, criminologists have developed "crime pattern theory" to study crime at the scale of neighborhoods or street blocks (e.g., Steenbeek & Weisburd, 2016; Summers & Johnson, 2017; Weisburd et al., 2009), cities (e.g., Sherman, Gartin, & Buerger, 1989), and countries (e.g., Farrell, 1998; Tseloni et al., 2004; Williams, 2015). Tilley and colleagues (2015) more closely considered the consequences of "target-hardening" (i.e., increasing the protection of) suitable targets. That is, when an intended change is made to the environment of a target (e.g., increased lighting in a neighborhood, a fence around a private property), crime rates related to the target dropped. In the context of regional drug trafficking operations, the typical conceptualization of a suitable target as an individual or property is theoretically limiting. Therefore, this study broadens the conceptualization of a "suitable target" to include geographic and physical landscape features that are conducive to the concealment or movement of cocaine shipments. These landscape features include proximity of trafficking routes to roadways and international borders, population density, the percentage of indigenous territory across the trafficking space, and the presence of international ports. By using this expanded conceptualization of target suitability, the study bridges criminological insights and land system science, by explicitly considering the logistical rather than productive value of the landscape.

2.2. Cocaine trafficking in Central America

The global supply of cocaine originates in South America, from where the drug is exported globally. A significant portion of South American cocaine production is exported out of Colombia through one or more of the Central American countries and Mexico, and from there to markets worldwide. The drugs are trafficked by land, sea, and air, sometimes with multiple modes used for a single shipment (Fig. 1). Central America has been a cocaine-trafficking waypoint since at least the 1970s; the region's importance as a transshipment hub grew in the mid-2000s, in part because interdiction activities cut off direct routes into Mexico, with a subsequent surge ca. 2007 in the number of shipments and the volume of cocaine smuggled first into Central America (Fig. 2). Mexican DTOs, as cocaine wholesalers, worked with Colombian suppliers and Central American associates to route more bulk (i.e., primary) shipments into the isthmus, and then move the drugs in smaller overland or coastal secondary shipments elsewhere, including into Mexico (UNODC, 2012).

Our ability to describe trends in cocaine trafficking through Central America relies on extensive field experience in the region and on data from the US government's Consolidated Counter Drug Database (CCDB). This obscure but unclassified dataset records all known cocaine trafficking events by air or water through the Western Hemisphere Transit Zone, including all of Central America (as well as the Caribbean, Eastern Pacific, and Mexico)[3]. The CCDB is a conservative baseline of total cocaine flow through the transit zone because it underrepresents a) smuggling in commercial shipments, b) areas that are not targeted by surveillance or other intelligence or operational assets, and c) overland shipments (McSweeney, 2020). Despite this conservatism, the dataset is unusual in recording all known trafficking events, no matter their outcome (i.e., whether the cocaine was seized, lost, or delivered) at subnational scale (GAO, 2002; Magliocca et al., 2019; McSweeney, 2020).

Data from the CCDB demonstrate the dynamism of trafficking routes and smuggling strategies over time and space within Central America. At the national level, for example, Guatemala and Panama received the largest total number of primary cocaine shipment from 2007 to 2018, followed by Costa Rica and Honduras. Nicaragua and El Salvador appear to receive relatively small amounts (Fig. 3). Those patterns reflect Guatemala's and Panama's logistical importance at the northern and southern ends of the Central American corridor, respectively. Further, recent Guatemalan administrations have been corrupted, enabling trafficking (Avalos, 2019). Panama, with its dollarized economy, tradition of banking secrecy, and transnational shipping infrastructure plays an important role in cocaine transshipment and in laundering of cocaine profits (Bunck & Fowler, 2012). Honduras was a particularly important transshipment point from 2009 to 2012—between the coup (which created a political vacuum attractive to traffickers) and the later U.S.-led interdiction response (Bosworth, 2010). Honduran politicians, military and elites nevertheless maintain significant involvement in the cocaine trade (IDRC, 2016), most dramatically illustrated in 2021 U.S. federal drug prosecutions, which directly implicate the sitting Honduran president (de Córdoba, 2021). Costa Rica has more recently emerged as a significant country of transshipment, in part as a 'spillover' effect as more northern bulk routes (i.e., into Honduras) were shut down by military activities. However, Costa Rica's role in the cocaine trade also reflects the ongoing diversification of cocaine markets beyond North America, as Costa Rica's ports become important in supplying European cocaine markets (McSweeney, 2020). El Salvador has likely been less attractive to traffickers due to its small size and to the presence of U.S. military installations on the Pacific Coast (IDRC, 2016). The relative lack of primary trafficking through Nicaragua may hide the importance of overland routes through the country.

2.3. Counterdrug interdiction

Within Central America overall, there are two primary types of counterdrug interdiction operations that influence and partially overlap in their responsibilities for cocaine trafficking detection and seizures. First, U.S.-based drug interdiction efforts include Department of Defense-run military bases on U.S. soil (e.g., Joint Inter-Agency South (JIATF-S) and in Honduras and El Salvador, radar installations, mobile assets (e.g., Army/Navy boats and planes) and Tactical Analysis Teams (TATs)), all of which contribute to the detection and monitoring of cocaine trafficking within the transit zone, while the Drug Enforcement Administration (DEA) and the U.S. Coast Guard have seizure and arrest powers. Drug interdiction operations by these agencies employ a range of techniques, equipment, and personnel, and are jurisdictionally limited to international waters. Maritime shipments of cocaine are frequently interdicted with a "force package" that includes a Coast Guard cutter, often with a Helicopter Interdiction Tactical Squadron on board, and supported by fixed wing aircraft for spotting vessels (GAO, 2018).

Second, Central American nations are also engaged in counterdrug interdiction efforts typically via police and military units, and often with significant operational, financial, intelligence-gathering, and training support from U.S. counternarcotic forces. Interdiction by these nations targets land routes and maritime shipments within their exclusive economic zones. These efforts can involve tactical operations directed at specific drug smuggling operations or personnel, or less targeted operations such as checkpoints and border inspections, and Central American counterdrug forces have reportedly become increasingly active in drug seizures (Faller, 2019). At the same time, cocaine traffickers are well-known to have deeply corrupted Central American governments for decades (Devine et al., 2018; Dudley, 2010; IRDC, 2016; McSweeney

[3] Although data exists for all these regions, the CCDB data is not curated and archived in a form that is conducive to time series analysis. Moreover, partial extracts of the CCDB are considered unclassified, but the CCDB as a whole rises to a classified security status. See McSweeney (2020) for more details. Consequently, our data extract from the CCDB at the *departamento* level and over the full study period is only a subset of the full database.

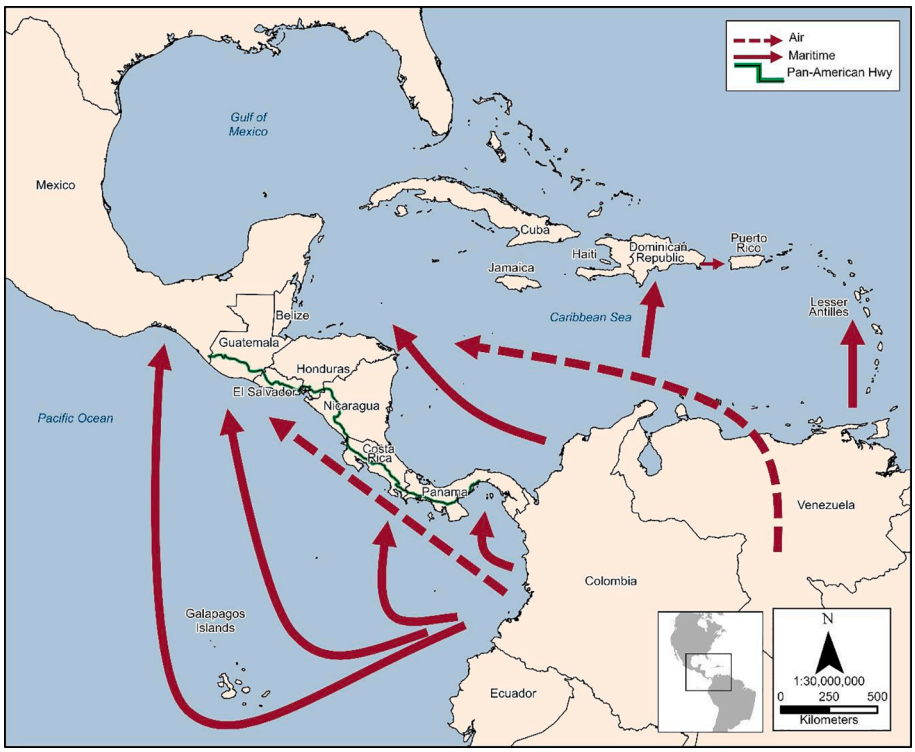

Fig. 1. Regional trafficking flows for primary cocaine shipments to Central America and Mexico. This geographic extent is considered the 'transit zone' for the North American market.

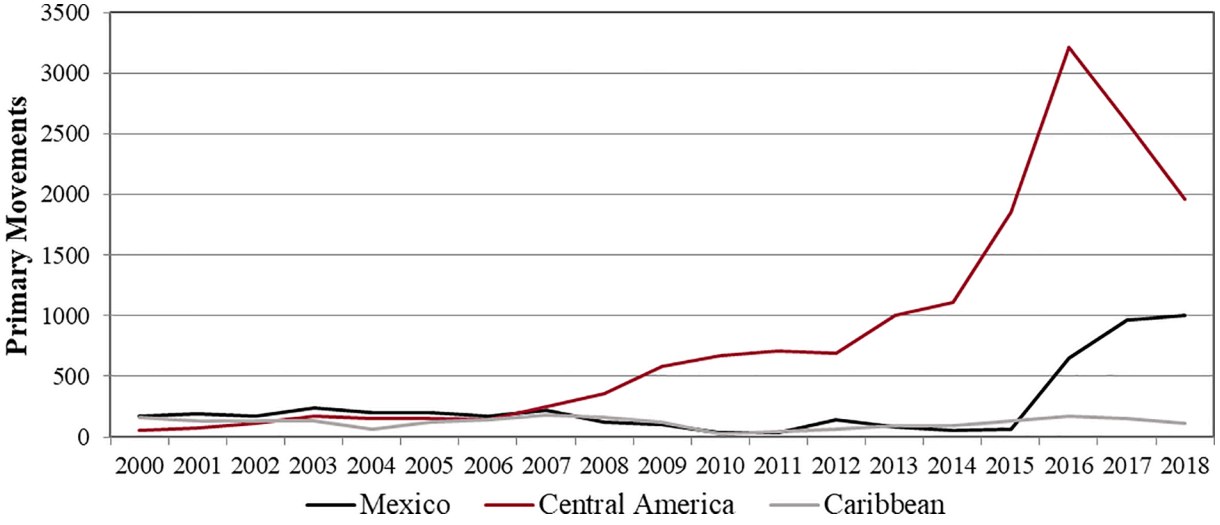

Fig. 2. Primary cocaine shipment movements by region 2007 – 2018.

et al., 2018). Along with traffickers' ability to adapt to interdiction enforcement spatially and organizationally, their success buying the complicity of state actors is considered one primary reason for the poor performance of interdiction throughout Central America (e.g., OIG, 2016).

3. Study objectives

This study examines variations in land suitability (i.e., suitable targets) between two time periods: before and after the place-specific moment of peak cocaine seizure volumes in each *departamento*. Specifically, the key objective is to comparatively analyze whether spatially varying landscape characteristics became more or less (or null) suitable for cocaine trafficking following a peak moment of "capable guardianship" (i.e., maximum observed cocaine seizure volumes) in 17 *departamentos* over a given time period (RQ). For example, geographic and physical landscape features may facilitate trafficking activities (e.g., proximity to rivers and coastline, high forest cover) or pose higher risk of law enforcement interdiction (e.g., population density). Based on prior research on the geo-spatial characteristics of cocaine trafficking in this

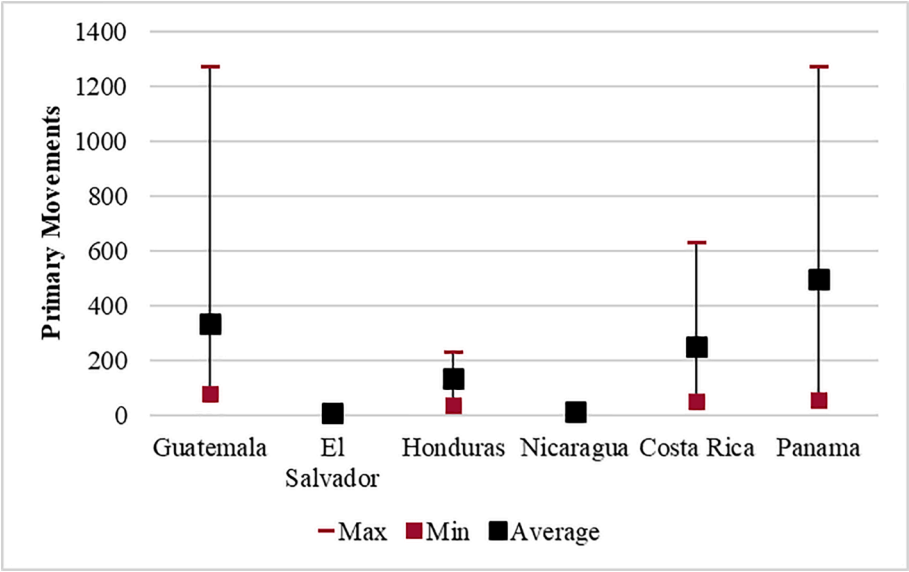

Fig. 3. Annual number of primary cocaine shipment movements by country 2007 – 2018.

region (e.g., McSweeney et al., 2018; Tellman et al., 2020a; Wrathall et al., 2020), as well as guidance from routine activities theory, we hypothesize two potential spatial and temporal patterns of suitability for cocaine trafficking. First, *departamentos* with (H1) closer proximity to international ports and borders and (H2) more efficient transportation via access to roads will have **relatively high and consistent suitability** for both primary and secondary trafficking uses (see 4.2, below). Second, *departamentos* (H3) that are relatively remote via low population density and (H4) where land governance is contested (measured by the percentages of indigenous territory and protected land) will have **relatively high suitability following peak interdiction** pressure.

4. Methods

To test these hypotheses, we used a multi-level, mixed effects negative binomial regression model to estimate spatially varying landscape suitability for narco-trafficking depending on the type and estimated volumes of cocaine shipments, time-varying success of counterdrug interdiction, and a series of biophysical, social, and political landscape characteristics. This was accomplished in two steps, each at a different spatial scale. Correlations between landscape characteristics and cocaine shipment volumes were first estimated at the level of subnational administrative units for two time periods defined relative to "peak interdiction" (described below). The regression relationships were subsequently used to estimate landscape suitability with disaggregate landscape characteristic data and for each time period.

Sub-national territories within Central American countries are known as *departamentos* in Guatemala, Honduras, and El Salvador, *provincias* in Costa Rica and Panama, and both *departamentos* and autonomous regions in Nicaragua; for simplicity, "*departamentos*" will be used henceforth. Fig. 4 displays the map of the transit zone countries in Central America, for which there are a total of 91 *departamentos*. However, we have reliable data on cocaine shipments from 2007 to 2018 for only 17 of those *departamentos* known from media coverage and prior research to include the most active trafficking hubs during the study period. Thus, shaded in grey in Fig. 4 are the *departamentos* for which continuous observations for the entire study period were reported in the CCDB and used in this study. All continuous landscape features were aggregated from 30-meter gridded datasets to the *departamento*-level.

Following routine activity theory, the effects of capable guardianship were investigated by dividing the study period into before and after the year of "peak interdiction" for each *departamento*, which was defined and operationalized as the year that the most cocaine (kg) was seized by law enforcement operations. A total of four models[4] were estimated for "before" and "after" peak interdiction for primary and secondary volumes. In Fig. 5, the vertical red lines indicate the peak interdiction year used to divide the full study period into before and after time periods for each *departamento* included in the study. For *departamentos* for which no clear peak in interdiction success was evident, the study period was divided evenly. Importantly, this variable was not empirically included in the regression analyses; instead, the year of peak interdiction for each *departamento* served as the point at which the timeline was divided into two segments, thus facilitating two separate regression analyses to be conducted to compare the pre- and post-impacts of heightened interdiction. For instance, in Limon, Costa Rica, the greatest amount of cocaine seized or lost due to counterdrug interdiction efforts was in 2013, which represents the year of peak interdiction for this *departamento*. Although counterdrug interdiction activities—on or off-shore—impacted the successful delivery of cocaine to each of these countries throughout the study period, the year of "peak interdiction" represents guardianship at its most capable point in time for each location. Since the environmental, physical, and political landscape features used to predict land suitability to traffickers (i.e., suitable spatial targets for smuggling) were relatively constant throughout the study period, changes in the estimated influence of those features between the before and after period were attributed to the effects of counterdrug interdiction activities by the U.S. or Central American law enforcement/militaries (i.e., guardianship). This supports a hypothesis that those activities lead to a reduction in the suitability of a given location and trigger traffickers' adaptation and relocation of their activities.

4.1. Independent Variables: Landscape suitability

"Landscape suitability" was operationalized with the following six independent variables: proximity to roads, proximity to international borders, the percentage of indigenous territory, the percentage of

[4] Employing interrupted time series analysis is not an appropriate method of analyses in this study; these tests require large numbers of observations to account for the loss of degrees of freedom when first differencing and/or lagging the variables (Enders, 1995). Given that the CCDB data we have is aggregated in annual increments, the timeline (2007 to 2018) does not yield the minimal number of observations (50+) necessary to conduct a robust time series analysis (Enders, 1995; Podesta, 2002).

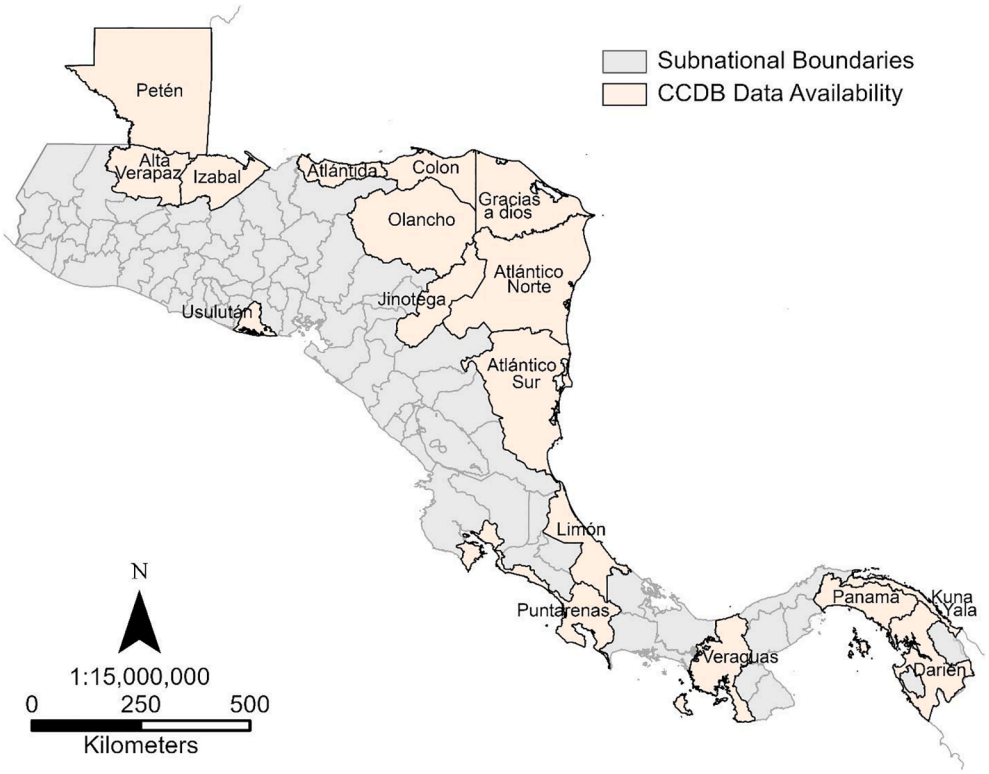

Fig. 4. Central American administrative units, or *departamentos*, included in this study.

protected land, population density, and the presence of international ports. These independent variables were chosen based on one or more of their known contributions to cocaine trafficking activities, such as ease of access to efficient and/or profitable transportation routes (given that these areas have existing transportation infrastructure), potential concealment of trafficking activities, and the ability to seize and control territory with impunity (Table 1). Continuous landscape features were derived from multiple sources: Global Administrative Areas (GADM), Global Forest Change Product (Hansen et al., 2013), Oak Ridge National Laboratory (ORNL), Open Street Map (OSM), United States Geological Survey Hydrologic data based on SHuttle Elevation Derivatives at multiple Scales (HydroSHEDS), International Union for Conservation of Nature (IUCN), the World Port Source (WPS), the Netherlands Enterprise Agency (NEA), and the El Salvador-based Regional Research Program on Environment and Development (PRISMA). All data were resampled or converted to gridded data with approximately1-km spatial resolution to be consistent with population density data and enable the continuous mapping of land suitability across space. All independent and dependent variables were also mean-normalized to improve regression model estimation.

Access to transportation infrastructure was represented as the minimum linear distance measured in kilometers (km) to the nearest road (i.e., *proximity to roads*), regardless of the size of road. Using formal roads reduces transportation costs or time in transit, which may increase profit and/or reduce the risk of detection.

Additionally, we considered the *proximity to international borders* to be an indicator of strategic and economic value; they are key transit points of increased risk but also increased profits, and remote and/or poorly enforced borders may be particularly attractive to traffickers (Allen, 2005; Keefe, 2013; Magliocca et al., 2019). This variable was measured as the linear distance (km) to the nearest international border.

The *presence of international ports* may also play an important role with the increased role of container shipping within transnational smuggling networks (Soudijn & Reuter, 2016; USDOJ, 2019; UNODC, 2012). Access to international ports was included in the analysis as either presence (1) or absence (0) within the *departamento*.

In addition to distance-based metrics, there are other landscape features that are likely to contribute to the suitability of landscapes for drug smuggling. Land tenure within and around protected land and indigenous territories (e.g., conservation areas and World Heritage Sites) is often unclear, contested, and/or subject to large disparities in political power among local communities and external actors (Ballvé, 2019; Blomley, 2003; Devine et al., 2018). Such contested spaces are attractive for cocaine trafficking, because territory can be seized and controlled relatively easily, and often without law enforcement repercussions (McSweeney et al., 2017; 2018; Wrathall, et al., 2020). The prevalence of such areas in each *departamento* was measured as the percentages of *departamento*-area contained within the boundaries of areas designated as *protected land* or *indigenous territory*. Because many landscape characteristics were clustered in space (e.g., population density), the median value of all grid cells within the boundaries of each *departamento* was used for the single *departamento* value in the regression analysis.[5]

Population density (the number of people per km^2) may also influence the suitability of spaces for cocaine trafficking operations (McSweeney et al., 2014, 2017; Tellman et al., 2020a). Population density was included in the analysis to test the suitability of remote (i.e., low population density) areas for avoiding law enforcement detection, but also the possibility that the presence of sufficient local labor (e.g., moderate population density) may be attractive for logistical needs, such as (un)loading shipments or clearing forest.

[5] While forest cover and terrain roughness may conceal trafficking activity (Ballvé, 2012; Devine et al., 2018), these variables were not included in the study due to collinearity with protected areas.

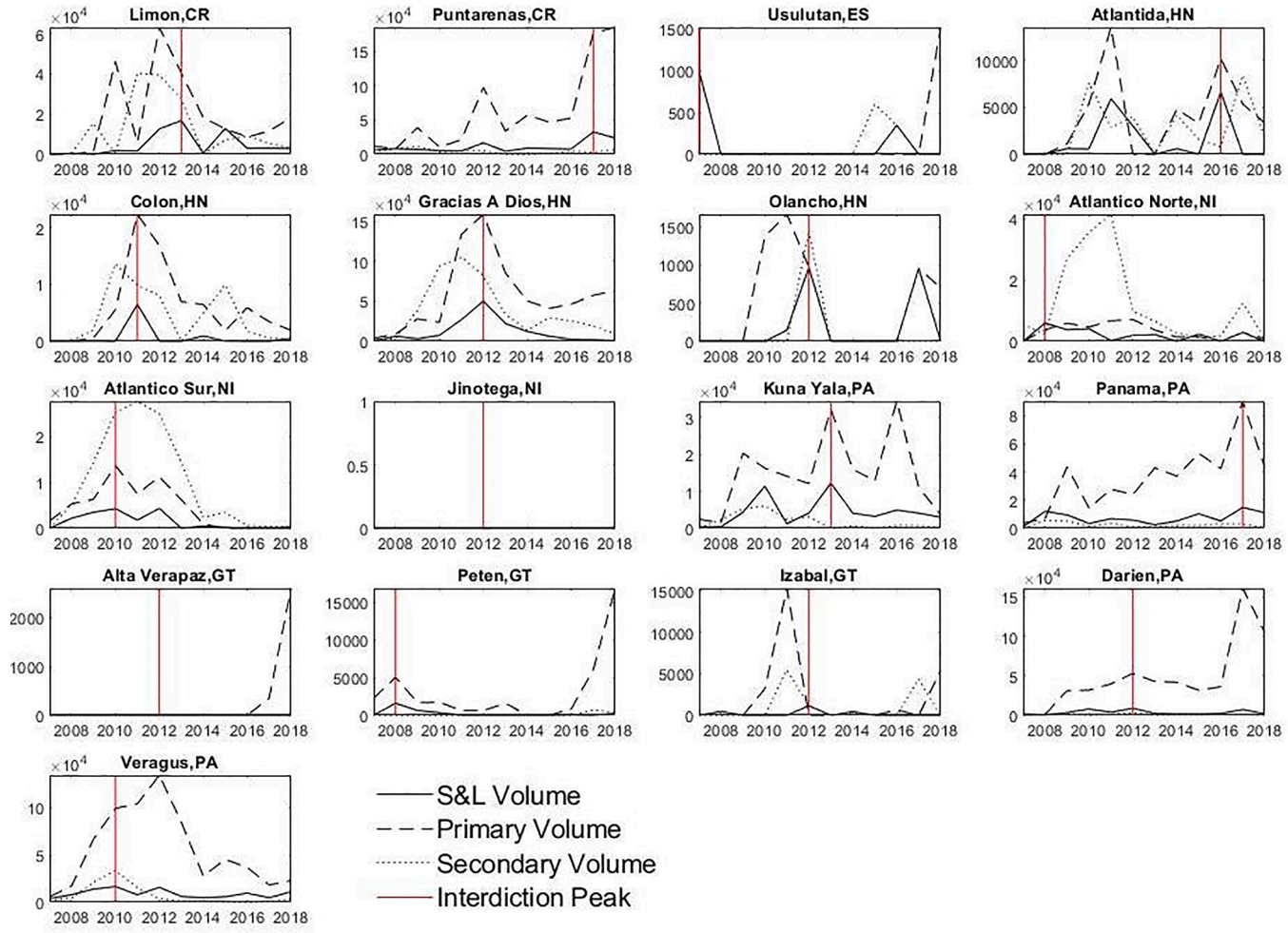

Fig. 5. Primary and secondary shipment volumes and seized and lost (S&L) shipment volumes from 2007 to 2018.

4.2. Dependent Variables: Primary and secondary cocaine trafficking patterns

The two dependent variables in this study were the spatially defined volumes of primary and secondary cocaine shipments within and through the 17 *departamentos* reported in the CCDB. *Primary movements* refer to cocaine shipments originating from a production location (i.e., South America) that are shipped into Central America; they are the first leg of cocaine export and are typically bulk shipments (700–900 kg) sent along maritime routes (in 'go-fast' boats, low-profile craft, semi-submersibles, and crude submarines) and along aerial routes via small aircraft (Fig. 1). A primary cocaine shipment that is delivered, seized, or lost is attributed in the CCDB to location indicated by intelligence as its intended destination. *Secondary movements* refer to subsequent, verified cocaine shipments from locations originating within the transit zone countries. When traffickers unload bulk cocaine from a primary shipment, they typically break up the load into smaller parcels that are sent in a greater number of transshipment events. These shipments are predominately transported over land using natural landscape features (e.g., rivers, mountain passes) and conventional infrastructure (e.g., the Pan-American Highway), or using short littoral zone (i.e., within national exclusive economic zones) movements along coastlines (UNODC, 2012). Both primary and secondary shipment volumes were quantified as the respective estimated volumes of cocaine shipments that were successfully delivered as reported in the CCDB.

4.3. Model design and evaluation

Typically, a Poisson distribution would be an appropriate modeling choice for count data like primary and secondary shipment volumes (Osgood & Chambers, 2000; Stucky & Ottensmann, 2009). However, due to the difficulties in observing and reporting on cocaine trafficking activities, the primary and secondary cocaine movement data was highly skewed in space and time and included many zero values, and thus was over-dispersed. A negative binomial model relaxes the assumption of no residual dispersion required for a Poisson distribution by including a dispersion parameter in the model (Stucky & Ottensmann, 2009). Comparing scaled residuals between Poisson and negative binomial model formulations confirmed over-dispersion of dependent variables, with the latter model substantially reducing scaled residuals to within acceptable ranges (Table 2). Additionally, a zero-inflated model was not selected, since zeros in the CCDB were defined as accurate reports of no cocaine shipments (i.e., true zeros).

A multi-level, mixed effects model specification was also used to account for relevant differences across national contexts. This formulation estimated random intercept terms accounting for unobserved effects unique to each country on total primary or secondary volumes (Finch et al., 2019). Additionally, cocaine shipments (particularly secondary movements) can be expected to move through contiguous space, producing spatial autocorrelations among shipment volumes in neighboring *departamentos*, and introducing spatially correlated errors in negative binomial models (Stucky & Ottensmann, 2009). To account for this spatial autocorrelation, we included a spatial lag variable

Table 1
Landscape suitability variables and data sources for Routine Activity Theory suitability mapping.

Variable	Theoretical Application	Description	Source (Date)
Proximity to roads	Suitable target (IV)	Distance from road network (km) as an indicator of opportunity to use as trafficking infrastructure.	Open Street Map (2019)
Proximity to international borders	Suitable target (IV)	Distance to international borders as an indicator of trafficking locations with high strategic and economic value (i.e., closer to border, higher value)	Global Administrative Areas (2018)
International ports	Suitable target (IV)	Presence of an international port within the department	WPS (2020); NEA (2018)
Protected areas and indigenous territories	Suitable target (IV)	Areas that have contested land governance and can be easily exploited by traffickers.	PRISMA (2014); UNEP-WCMC and IUCN (2020)
Population density	Suitable target (IV)	Population density is used as a proxy for and is inversely related to remoteness. Derived from Landscan 2000 data product (ppl km^{-2}).	Bright and Coleman (2001)
Primary and secondary cocaine flows	Dependent variables	Volume of cocaine seized, lost, or delivered per CY (2007–2018) in select departments.	CCDB (2007–2018)
Peak interdiction year	Capable Guardianship	Year of maximum reported seizures or losses of cocaine shipments due to interdiction forces.	CCDB (2007–2018)
Country dummy	Control variable	Dummy variable to capture differences in institutional quality, strength of land governance, and cooperative agreements with U.S.-led interdiction forces	

Table 2
Scaled residuals ranges of Poisson and negative binomial regression models.

	Before Peak Interdiction		After Peak Interdiction	
Outcome Variable	*Poisson Model*	*Negative Binomial Model*	*Poisson Model*	*Negative Binomial Model*
Primary Volume	[−6.91,13.0]	[−1.45,2.26]	[−9.25,12.5]	[−1.43,1.37]
Secondary Volume	[−7.45,13.3]	[−1.02,2.57]	[−8.22,9.88]	[−1.03,3.16]

(Fotheringham et al., 2000; Wang, 2007), which accounted (to the extent possible) for the increased likelihood of cocaine shipments moving though a given *departamento* if shipments were moved through any of its neighboring *departamentos*. The spatial lag for each *departamento* was calculated as the average shipment volumes of any adjacent *departamentos* for which shipment volume was available weighted by distance. Multi-level, mixed effect negative binomial models were estimated using maximum likelihood methods computed with the 'glm.nb' package in R software (Venables & Ripley, 2013).

4.3.1. Intercept-Only model

The first step in the inferential analysis was estimating a multilevel, mixed effects negative binomial regression model that included no landscape characteristics at the *departamento* level as predictors. In other words, the first model explored only the independent effects of countries on the suitability of *departamento*-level shipment volumes. This permits testing the hypothesis that spatially varying landscape characteristics became more or less (or null) suitable following a peak in capable guardianship (i.e., interdiction of cocaine by law enforcement) in each of the 17 *departamentos*. The purpose of the country-level model was to determine whether unobservable country-level conditions explained variation in *departamento*-level shipments, and to estimate model fit statistics for comparisons with the full model. Moreover, this first step investigated whether multilevel modeling was appropriate by determining if the variance of the intercepts vary significantly across countries. Eq. (1) shows the model specification for the country-level, intercept-only (i.e., 'null') model.

$$\eta_{ij} = \beta_j + \varepsilon_{ij} \tag{1}$$

The log-link function of the *departamento*-level shipment volumes (η_{ij}) is a function of the intercept (β_j) plus a *departamento* specific error term (ε_{ij}) that measured the difference between each *departamento*'s (i) shipment volumes and the predicted shipment volumes within each (j) country.

Eq. (2) shows the intercept (β_j) is a function of (γ_0), which was the overall average shipment volume across all of the countries considered, plus an error term (μ_{0j}) that measured variation in country intercepts around the overall average cocaine shipment volumes (γ_0).

$$\beta_j = \gamma_0 + \mu_{0j} \tag{2}$$

When Eq. (2) is substituted into Eq. (1) we arrive at Eq. (3), which is the fully specified null model.

$$\eta_{ij} = \gamma_0 + \mu_j + \varepsilon_{ij} \tag{3}$$

The results of the intercept-only country-level model revealed that the variance component of the intercepts for primary and secondary cocaine shipment volumes was significant, indicating that country differences were important for modeling *departamento*-level shipment volumes and a multilevel modeling approach was appropriate.

4.3.2. Mixed-Effects model

Next, randomcoefficients with adjustments for overdispersion and spatial dependency were estimated to explore how the effects of landscape characteristics at the *departamento* varied across countries. In the full model, slopes were allowed to vary across *departamentos* (random or 'cluster-specific' effects (Gelman, 2005)), and fixed, or 'population-level' (Gelman, 2005), effects at the country-level were included to control for unobservable conditions across countries. Eq. (4) shows the multi-level, mixed effects regression equation for the mixed-effects model.

$$\eta_{ij} = \beta_j + \beta_{ij}(X_{ij}) + \rho(y_{ij-1}) + r_{ij} \tag{4}$$

where the log-link of cocaine shipment volumes (η_{ij}) is a function of the intercept (β_j), a vector of *departamento* predictors (X_{ij}), a spatially lagged dependent variable (y_{ij-1}), and a *departamento* specific error term (r_{ij}) that measured the difference between each *departamento*'s (i) shipment volumes and the predicted shipment volumes within each (j) country. Eq. (5) shows the country-level regression equation where the intercept from Eq. (4) is a function of country conditions.

$$\beta_j = \gamma_0 + \gamma_j(W_j) + \mu_{0j} \tag{5}$$

The intercept (β_j) is a function of the grand mean (γ_0) plus a vector of country fixed effects (W_j) and an error term measuring the difference between the intercept of each country and the grand mean across all countries (μ_{0j}). Eq. (6) shows the slope β_{ij} is a function of a vector of

departamento independent variables (X_{ij}) plus an error term (μ_{1j}) measuring the difference between the slope in any (j) country and the overall slope across all countries. Eq. (6) also shows the slope for the spatial lag (ρ) among *departamentos* is a function of the effects of the spatial lag plus an error term measuring the difference between (γ_2) and the overall effect of the spatial lag across all countries.

$$\beta_{ij} = \gamma_1(X_{ij}) + \mu_{1j} \tag{6}$$

$$\rho = \gamma_2(y_{ij-1}) + \mu_{2j}$$

Eq. (7) shows the model specification for the full multi-level, mixed effects model that includes all predictors and both random and fixed effects.

$$\eta_{ij} = \gamma_0 + \gamma_j(W_j) + \gamma_1(X_{ij}) + \gamma_2(y_{ij-1}) + \varepsilon_{ij} \tag{7}$$

$$\varepsilon_{ij} = \mu_{0j} + \mu_{1j} + \mu_{2j} + r_{ij}$$

where the natural log of primary or secondary shipment volumes (η_{ij}) is a function of the grand mean (γ_0) plus a vector of country-level fixed effects (W_j) that were invariant within countries, a vector of *departamento* independent variables (X_{ij}) that varied across countries, a spatially lagged dependent variable (y_{ij-1}), and error terms (ε_{ij}) measuring the variance of country intercepts around the grand mean (μ_{0j}), variance of the slopes of *departamento* predictors across countries (μ_{1j}, μ_{2j}), and residuals of *departamentos* around country specific slopes (r_{ij}).

Overall model fit was evaluated by conducting a likelihood ratio test between null and minimum model formulations. *Minimum* models were constructed by removing collinear predictor variables until variance inflation factors (VIF) for each predictor were below the threshold value of 5 (O'Brian, 2007). Additional predictor variables were removed that might introduce spurious or confounding correlations while not increasing VIF values above the threshold. Minimum model specifications were retained based on minimization of the Akaike Information Criterion (AIC) and statistically significant improvements in log likelihoods after removal of each additional predictor variable compared with the chi-squared distribution (Osgood & Chambers, 2000). *Null* models included only the random intercept of country.

Estimated suitability values before and after peak interdiction were evaluated in comparison with measures of the consistency and magnitude of reported primary and secondary cocaine movements. Using Shannon's equitability (Magurran, 1988; Rosenweig, 1995), shipment volume equity measured how consistently cocaine movements were reported throughout each analytical period (i.e., time span before/after peak interdiction). The magnitude was calculated as the rank (as percentile) of the maximum amount of cocaine seized, lost, or delivered (i.e., the flow) observed in the given *departamento* relative to this measure observed across all *departamentos* during the same analytical period. This measure provided insight into the maximum intensity of primary or secondary movements in a given *departamento* independent of shipment evenness. Together, these two metrics provided insight into the dynamics of primary and secondary cocaine movements before and after peak interdiction to aid interpretation of changes in suitability. Results of this assessment are reported for select *departamentos* in the next section and all *departamentos* in Appendix A.

5. Results

5.1. Land suitability for primary cocaine shipments

In the period before the peak interdiction year, *departamentos* with lower population densities and greater proximity to international borders were those most favored by traffickers for receiving bulk shipments—that is, they had higher suitability and predicted primary shipment volumes (Table 3). The presence of transportation infrastructure (measured as proximity to roads and the presence of international ports), did not significantly influence suitability, nor did the presence of trafficking in neighboring *departamentos* (spatial lag). A greater share of land in protected status (percent protected area) lowered a *departamento*'s suitability and thus appeared to be a weak deterrent of primary shipments. This was likely most attributable to the positive correlation between the percent of *departamento* area in protected status and proximity to the coast (Table 3).

Table 3
Multi-level, mixed effect negative binomial regressions of primary shipment volumes before and after each department's (n = 17) peak interdiction year.

	Before Peak Interdiction	After Peak Interdiction
	Estimate	**Estimate**
Random effects		
Country Intercept		
Costa Rica	$4.04 * 10^{-13}$	$2.67 * 10^{-12}$
El Salvador	$1.23 * 10^{-13}$	$4.32 * 10^{-13}$
Guatemala	$-7.63 * 10^{-13}$	$-2.48 * 10^{-12}$
Honduras	$5.46 * 10^{-13}$	$5.65 * 10^{-13}$
Nicaragua	$9.08 * 10^{-14}$	$-2.21 * 10^{-13}$
Panama	$-4.00 * 10^{-13}$	$-9.65 * 10^{-13}$
Conditional Std. Error	$(5.18*10^{-7})$	$(1.60*10^{-6})$
Fixed Effects		
Intercept	7.30***	6.82***
	(0.76)	(0.77)
Spatial Lag	0.62	0.43
	(0.81)	(0.93)
Proximity to Roads	−1.09	−0.87
	(1.15)	(1.15)
Population Density	−2.98***	−2.32**
	(0.84)	(0.82)
Percent Indigenous Territory	0.33	1.14^{+}
	(0.63)	(0.60)
Percent Protected Area	−1.38^{+}	−1.58^{+}
	(0.80)	(0.84)
Proximity to Intl. Border	−5.47***	−3.22***
	(0.91)	(0.91)
Intl. Port (yes/no)	−0.08	−0.45
	(0.39)	(0.41)
Log Likelihood	−99.9	−103.1
AIC	219.8	226.2

Note: Standard errors in parentheses.
* $p < 0.1$; ** $p < 0.01$; ***$p < 0.001$

These results provided mixed support for our hypotheses. Locations with low population density (H3) and proximity to international borders (H1) were more suitable for cocaine trafficking before peak interdiction, which supported the hypothesis that some remote areas in strategic locations close to border crossings were preferred by traffickers. However, contrary to this hypothesis, close proximity to transportation infrastructure (H2: roads, rivers, and coastlines) and the presence of international ports (one element of H1) were not associated with higher primary shipment volumes, and areas of contested governance (H4: percentage of indigenous territory, percentage of protected land) were weak deterrents of, or not associated with, primary cocaine movements.

Application of the regression model coefficients to spatially disaggregated data produced the suitability map in Fig. 6. Land suitability prior to the first peak in interdiction approximated terrain roughness, such as the western uplands of Guatemala bordering Mexico which were among the highest suitability locations. Suitability was also high among most East Pacific and northern Honduran coastal *departamentos*, which are known trafficking hotspots (e.g., McSweeney et al., 2018). In particular, Gracias a Dios in northeastern Honduras, which is known to contain many clandestine airstrips that were active in the beginning of the study period, stood out as a highly suitable areas surrounded by low to moderate suitability areas. The lowlands of Costa Rica's Caribbean and Pacific coasts also had moderately high suitability. Notable areas with low suitability include southeast Panama (Darién), southeast Nicaragua (Atlántico Sur), and northern Guatemala (Petén), which all contain a high proportion of conservation areas, including biosphere

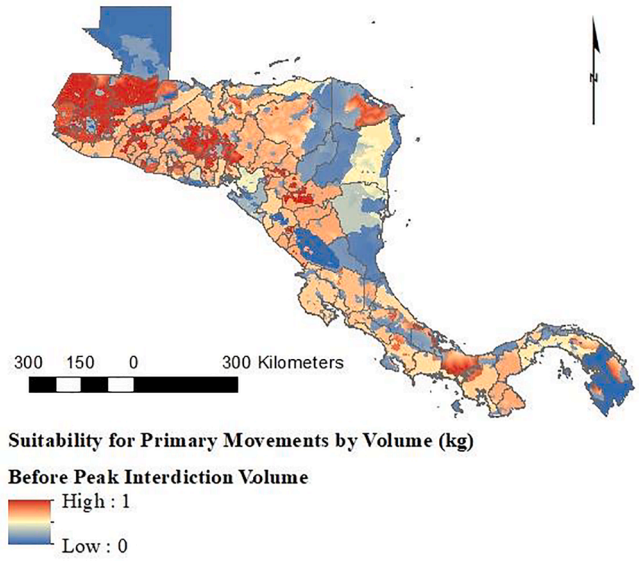

Fig. 6. Suitability map for primary shipment volumes before peak interdiction.

reserves.

The landscape features that influenced suitability before peak interdiction remained statistically significant predictors of primary shipment volumes and suitability after peak interdiction, i.e., after traffickers' activities were most disrupted by law enforcement activities. The suitability of locations with low population density and proximity to international borders were generally insensitive to the peak in interdiction and remained highly suitable in both analysis periods. Primary shipment volumes in neighboring *departamentos* also did not predict primary shipment activity in the target *departamento*. However, *departamentos* with higher proportions of indigenous territory were substantially more suitable after peak interdiction than before.

The suitability map in Fig. 7 shows additional evidence for spatial shifts in primary shipment after peak interdiction. Many more areas of moderate and high land suitability were evident before peak interdiction, suggesting perhaps a concentration of activity and/or an increase in law enforcement awareness in highly suitable areas after peak interdiction. After the peak of interdiction, highly suitable locations

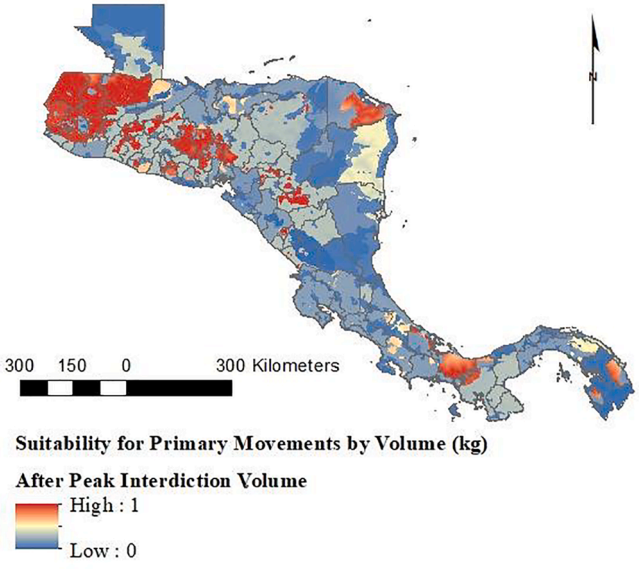

Fig. 7. Suitability map for primary shipment volumes after peak interdiction.

were concentrated in remote/rugged terrain and/or in indigenous territories and outside of protected areas.

5.2. Land suitability and secondary cocaine movements in the Central American corridor

Prior to peak interdiction, strong inverse relationships were detected with secondary cocaine movements and population density (H3), proximity to international borders (H1), and areas of contested governance (H4). In other words, traffickers moving smaller volumes of drugs overland typically avoided populated areas, conservation areas, and indigenous territories and favored border zones (Table 4). Slightly weaker, negative relationships among secondary cocaine shipments and proximity to roads and the presence of an international port were also identified (H2). Greater proportions of indigenous territory within a *departamento* and increased trafficking activity in neighboring *departamentos* (spatial lag) moderately increased the suitability for secondary shipments. Spatial correlation of secondary shipments reflected the general tendency for secondary movements to occur over land following spatially contiguous routes (Table 4). These findings were all consistent with the factors predicted in our four hypotheses.

The suitability map for secondary shipments before peak interdiction highlights contiguous areas of moderate to high suitability (Fig. 8). Similar to primary shipment suitability, the western uplands of Guatemala were again highly suitable. Two Caribbean trafficking corridors reported in the literature (Dudley, 2010; McSweeney et al., 2017; 2018) were mapped as contiguous suitable areas. The Caribbean coast of Honduras, from Colón department, and extending westward into Izabal, Guatemala ranged from moderate to high suitability, and inland areas of the Miskito Coast, extending from Gracias a Dios, Honduras in the north through Atlántico Norte, Nicaragua in the south, had generally high suitability. The lowlands of Costa Rica's Caribbean and Pacific coasts also had moderately high suitability. Petén, Guatemala and the interior

Table 4
Multi-level, mixed effect negative binomial regressions of secondary shipment volumes before and after each department's (n = 17) peak interdiction year.

	Before Peak Interdiction	After Peak Interdiction
	Estimate	Estimate
Random effects		
Country Intercept		
Costa Rica	$3.72 * 10^{-13}$	$-5.92 * 10^{-14}$
El Salvador	$1.94 * 10^{-13}$	$2.39 * 10^{-14}$
Guatemala	$-3.44 * 10^{-12}$	$-2.53 * 10^{-13}$
Honduras	$-2.30 * 10^{-14}$	$-3.02 * 10^{-14}$
Nicaragua	$2.15 * 10^{-12}$	$2.39 * 10^{-13}$
Panama	$7.41 * 10^{-13}$	$8.00 * 10^{-14}$
Conditional Std. Error	$(1.10*10^{-6})$	$(3.90*10^{-7})$
Fixed Effects		
Intercept	6.06***	4.87***
	(0.81)	(0.89)
Spatial Lag	2.67**	2.41*
	(0.83)	(0.96)
Proximity to Roads	-2.00^{+}	−3.62**
	(1.17)	(1.18)
Population Density	−4.53**	−1.15
	(1.45)	(1.05)
Percent Indigenous Territory	1.63*	1.82*
	(0.82)	(0.81)
Percent Protected Area	−3.18***	−0.08
	(0.92)	(1.00)
Proximity to Intl. Border	−5.10***	−5.62***
	(1.18)	(1.33)
Intl. Port (yes/no)	−1.16*	0.90
	(0.49)	(0.59)
Log Likelihood	−89.5	−89.2
AIC	199.1	198.5

Note: Standard errors in parentheses.
* $p < 0.1$; ** $p < 0.01$; ***$p < 0.001$

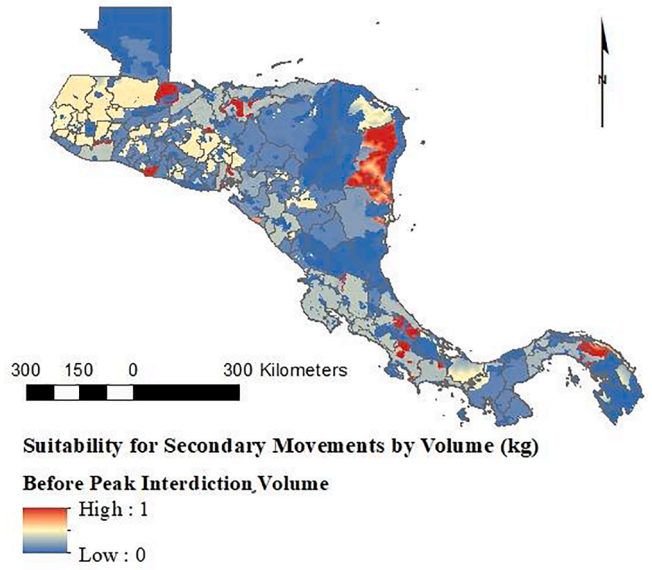

Fig. 8. Suitability map for secondary shipment volumes before peak interdiction.

of Honduras and Nicaragua generally resulted in low suitability.

After peak interdiction, the importance of population density and percent protected area for predicting suitability for secondary cocaine movements waned substantially (Fig. 9). Both landscape characteristics shifted from strong negative relationships before peak interdiction to being no longer statistically significant after peak interdiction. In addition, proximity to roads grew in importance and international ports were no longer a deterrent after peak interdiction. These shifts also suggested that higher population densities were no longer a deterrent for secondary shipments after peak interdiction. New areas increased suitability after peak interdiction, which suggests that certain locations may have transitory suitability dependent on pressure from interdiction in a given location and elsewhere in the trafficking network. There was also evidence that some locations remained highly suitable even after peak interdiction, which was consistent with our third hypothesis and findings from primary shipments.

Overall, both before and after peak interdiction land suitability levels were strongly influenced by spaces of contested or weakened land tenure, such as protected areas and indigenous territories, illustrating the importance of sovereign landscape features for understanding variations in the attractiveness of particular spaces to traffickers. Land suitability for both primary and secondary cocaine shipments underwent statistically significant shifts before and after peak interdiction, demonstrating the role of capable guardianship in altering the suitability of spaces for cocaine trafficking. Additionally, spatially extrapolating the modeled suitability coefficients showed a concentration of highly suitable locations between before and after peak interdiction periods for both primary and secondary shipments.

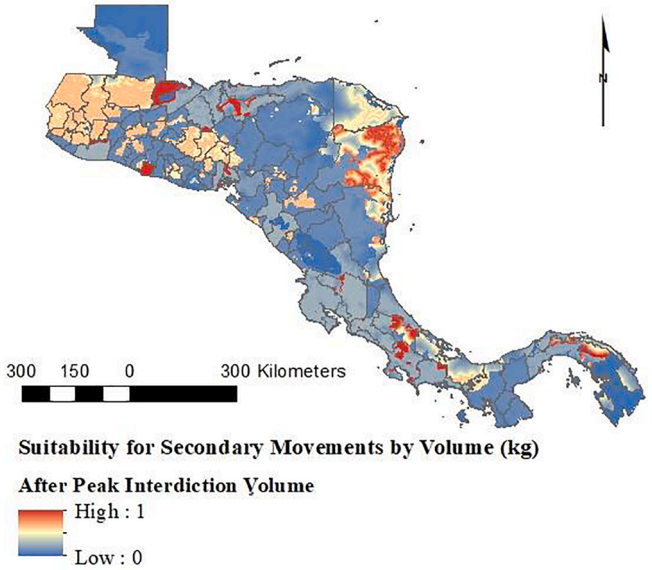

Fig. 9. Suitability map for secondary shipment volumes after peak interdiction.

Conversely, more locations appeared to have lower suitability after peak interdiction. This trend suggested that interdiction decreased the landscape suitability of these spaces. However, this finding must be interpreted with caution due to the inherently dynamic nature of cocaine trafficking and limitations of a two-period spatial analysis. Relatively low suitability values could have been produced two ways: 1) cocaine secondary movements were relatively low or absent throughout the analysis period (true negatives); or 2) higher secondary cocaine movements persisted only a short time and/or were easily displaced by interdiction, and such dynamics were averaged out over time (false negatives). The latter explanation is consistent with findings about the adaptive responses of traffickers to interdiction (Magliocca et al., 2019). Low suitability values could have been produced by the intensification of trafficking along specific routes resulting in larger shipment volumes for a condensed amount of time in any given location.

To resolve this potential conflation of mechanisms and tease out the true effects of interdiction on landscape suitability, metrics describing the consistency and relative magnitudes of shipments were compared with suitability model predictions before and after peak interdiction for the 17 *departamentos* in this study. Selected *departamentos* that experienced suitability declines from before to after peak interdiction are presented in Tables 5 and 6 (see Appendix A for *departamento*-specific results). All possible alternative cocaine trafficking dynamics that led to decreased suitability estimates were observed. For example, suitability in Limón, Costa Rica decreased between peak interdiction analytical periods for both primary and secondary shipments due to consistent but smaller shipment volumes after peak interdiction. Primary shipment suitability decreased for Izabal, Guatemala and Olancho, Honduras due to decreased shipment volumes after peak interdiction, and additionally a decrease in the consistency of shipments over time in Olancho (Table 5). For secondary shipment volumes (Table 6), suitability decreased in Izabal due to more sporadic shipments after interdiction. In contrast, suitability for secondary shipments in Guna Yala, Panama decreased due to smaller shipment volumes after peak interdiction despite the same frequency of shipments.

6. Discussion

With the guidance of routine activity theory, this study empirically examined how cocaine trafficking routes through Central America changed in relation to landscape features following significant interdiction activity by law enforcement agencies. The study yielded at least three key insights.

First, there were discernable differences in the contributions of landscape features to suitability for cocaine trafficking for both primary and secondary shipments. For instance, we found that no matter where traffickers were in the supply chain (i.e., receiving bulk or smaller secondary shipments), they were most likely to be drawn to those *departamentos* with lower population densities and those that were closer to international borders. As prior research has also shown, this work confirmed that bulk, primary cocaine shipments were most likely to land in *departamentos* with abundant remote locations and along sparsely populated coastlines (McSweeney et al., 2017, 2018; Sesnie et al., 2017). However, once traffickers started moving the drugs overland (i.e., secondary shipments), transshipment hubs were more likely to be

Table 5
Comparison of suitability values for primary shipments with metrics of reported shipment characteristics for select departments with decreased suitability before and after peak interdiction.

Department	Peak Interdiction Analytical Period	Median Suitability	Volume Equity	Maximum Volume Percentile	Interpretation of Decreased Suitability
Limón, CR	Before	0.58	0.64	0.92	Consistently smaller shipments
	After	0.19	0.98	0.68	
Izabal, GT	Before	0.62	0.32	0.74	Decreased volume of shipments
	After	0.19	0.32	0.52	
Olancho, HN	Before	0.64	0.60	0.43	Decreased consistency and volume of shipments
	After	0.29	0.38	0.36	

Note: Primary shipment volume equity measures the consistency of shipments over time and maximum volume percentile measures the magnitude of the department's shipments relative to all others.

Table 6
Comparison of suitability values for secondary shipments with metrics of reported shipment characteristics for select departments with decreased suitability before and after peak interdiction.

Department	Peak Interdiction Analytical Period	Median Suitability	Volume Equity	Maximum Volume Percentile	Interpretation of Decreased Suitability
Limón, CR	Before	0.17	0.69	0.96	Consistently smaller shipments
	After	0.14	0.82	0.91	
Izabal, GT	Before	0.18	0.26	0.72	Decreased consistency of shipments
	After	0.15	0.09	0.81	
Guna Yala, PA	Before	0.26	0.79	0.76	Decreased volume of shipments
	After	0.21	0.79	0.57	

Note: Secondary shipment volume equity measures the consistency of shipments over time and maximum volume percentile measures the magnitude of the department's shipments relative to all others.

associated with more transportation infrastructure in the forms of roads and international ports. Several locations known to be narco-trafficking hotspots (McSweeney et al., 2018; Devine et al., 2018), such as the western uplands of Guatemala and coastal corridors in Honduras and Costa Rica, were also insensitive to interdiction pressure and remained highly suitable for primary and secondary shipments before and after peak interdiction.

Second, traffickers were more inclined to move their activities to *departamentos* with relatively abundant protected areas and indigenous territories after peak interdiction. Many of the protected areas and particularly indigenous territories targeted for primary shipments later in the study period (e.g., in the Petén and Gracias a Dios) are characterized by a combination of relative remoteness, land abundance, flat terrain, and thin rural populations. Combined, these traits made them highly attractive to traffickers seeking to move bulk cocaine far from major population centers (and thus law enforcement), in spaces that are amenable to plane, truck, and boat traffic. At the same time, poor and disenfranchised indigenous populations in these locations are susceptible to economic and physical coercions. This finding is consistent with accounts in the literature of transgressions into and dispossession of indigenous land by drug trafficking groups ((Devine, 2014); Magliocca et al., 2019; McSweeney et al., 2017, 2018; Tellman et al., 2020b; Wrathall et al., 2020).

Third, secondary cocaine shipments favored *departamentos* with higher population densities and better road and port access after interdiction. This trend mirrors anecdotal reports in Guatemalan, Honduran, and Nicaraguan media regarding increased cocaine seizures in populated areas utilizing transportation infrastructure (e.g., Pan-American highway, airports, international ports) (Tellman et al., 2020b). This potentially demonstrates the need by cocaine trafficking networks to enlist local residents (voluntarily or by force) to support trafficking logistics, and/or to hide from law enforcement among the masses enabled by better concealment of smaller shipments.

6.1. Study limitations

This study relied on trafficking-related data archived in the 'cocaine module' of the CCDB. While this dataset provided reliable numbers for the *departamentos* that report data —it is carefully vetted to minimize the likelihood of false positives—it also known to underestimate the total number of trafficking events into and especially through the Central American corridor. The magnitude of that undercount is unknown (GAO, 2002; McSweeney, 2020). Further, our data relied on only a subset of all *departamentos* for which CCDB data was obtained. Combined, these factors mean that our analysis is based on the best available but nevertheless incomplete picture of cocaine movements in the study area.

Additionally, we acknowledge that there is a mismatch between the spatial scales at which the CCDB data is available and landscape characteristics are described (*departamento*) and the disaggregated suitability maps (1 km). Several independent variables that were calculated at finer spatial resolutions and then aggregated to the *departamento* level for statistical analysis, such as proximity to roads and international boards and population density, suffer from the modifiable area unit problem (MAUP) (Openshaw, 1984). In other words, these variables measure different things at different spatial scales. For example, the median proximity to roads at the *departamento* level estimates the influence of that *departamento*'s level of infrastructure on suitability, specifically how much of it there is and how evenly it is spread, which is not an equivalent estimate of a given pixel's suitability based on its proximity to roads within that *departamento* (which may depart substantially from the aggregate value for the department). For these reasons, individual pixel suitability values do not have any absolute meaning, but rather should be interpreted based on qualitative, relative differences among locations. Despite this limitation, the disaggregate suitability mappings are useful for three reasons. First, disaggregate suitability values do not qualitatively change the interpretation of *departamento*-level variations in pre- and post-peak interdiction suitability. The disaggregate suitability values are, second, useful for visualizing spatial patterns of suitability associated with various landscape features, many of which extend beyond the administrative boundaries of *departamentos*. Third, aggregate suitability values for each *departamento* are not particularly informative by themselves, as cocaine trafficking does not occur between *departamentos* but rather along geographically defined routes that leverage landscape vulnerabilities. While our disaggregate suitability analysis cannot provide a defensible estimate of

the absolute suitability of specific landscape features, it does illustrate qualitative differences across space and time that are helpful for illustrating which landscape features are relatively more and persistently attractive for narco-trafficking.

Additionally, this study acknowledges that the operationalization of "guardianship" - measured as the volume of cocaine seized by law enforcement - is not a complete representation of all cocaine traversing the landscapes, nor can this study approximate the ratio of cocaine seized to total flows in these areas. The seizure of cocaine in this measure is completely dependent upon the actions of law enforcement officers; thus, issues of corruption within the agencies and lack of or variation in narco-training and identification of cocaine smuggling techniques, for instance, will undoubtedly vary and may impact the total amount seized. Guardianship, then, is represented by the amount of cocaine removed by capable guardians in the Central American countries included in this study, thus negatively impacting (i.e., theoretically deterring or dissuading) trafficking operations in areas of seizures. The level of effectiveness of agencies seizing cocaine in Central America will vary from law enforcement agencies in other countries, such as the United States, but other factors related to the country's location in proximity to the source of the illicit product, also needs to be considered (e.g., the U.S. is a retail market, whereas Central American countries are transit zones). Regardless, the operationalization of guardianship used in this study is consistent with prior applications in criminology, as illustrated by work conducted by Reynald, 2016; Sherman, Gartin, & Buerger, 1989; Steenbeek & Weisburd, 2016; Weisburd et al., 2004, and others (e.g., (Drawve, Thomas, & Walker, 2014)).

Finally, the dynamic nature of cocaine trafficking activities cannot be fully captured using aggregate statistical models of suitability. Specifically, moderate to low suitability values can mask different scenarios of trafficking activity. For example, two alternative shipment dynamics could produce moderate suitability values for a given department. Cocaine shipments could move through a given department consistently but at low shipment volumes relative to those in other departments at the same time. Alternatively, cocaine shipments volumes could be relatively large but concentrated in time (e.g., 1 to 3 years). Both of these scenarios would indicate a location suitable for trafficking, but would receive low to moderate suitability estimates because average shipment volumes over time would be relatively low. The evaluation of decreases in low to moderate suitability values following peak interdiction (see Tables 5 and 6 and Appendix A) allowed us to distinguish whether changes in shipment volume or consistency over time were responsible, which improved our interpretation of before and after peak interdiction changes for particular landscapes that were known trafficking hotspots at some point in time.

6.2. Policy implications

Broadening the understanding of the interactions of land suitability and drug trafficking activities has the potential to change both drug interdiction operations and the policies that drive those operations. The findings of this study can directly inform the development of actionable policies to more effectively address the behavioral reactions of traffickers and the movement of their product to reduce harm in local communities caused by drug use, violence, corruption, and environmental degradation caused by primary and secondary cocaine trafficking.

Since interdiction resources are often severely limited with respect to the large amount of trafficking activity, knowing which landscape features will be viewed as more appealing by traffickers can guide when and where those limited resources are deployed. To optimize resource allocation, this study proposes that the governments in Central American countries focus on policy development in two key areas. First, knowing where trafficking routes are likely to shift following significant interdiction activity should be used to anticipate preventative measures that could be enacted prior to major interdiction operations. For example, this study found that primary trafficking activities preferentially occurred in or where destined for *departamentos* with substantial remote areas, which, in some cases, shifted into indigenous territories following law enforcement intervention. Instead of continuing to monitor trafficking in large cities, surveillance and enforcement efforts should be redirected to these rural locations, and aid be afforded to local communities and their representatives to shore up against trafficker infiltration. As data collection improves in each *departamento*, agencies will be better able to identify specific route alterations in trafficking activity in their jurisdiction following each operation, enabling the fine-tuning of resource allocation to disrupt trafficking activities. Using these models to better target drug trafficking organizations in each country will also lead to a greater need for effective international cooperation, particularly as this study found the increased likelihood of cocaine trafficking routes moving towards international borders.

Second, in line with routine activity theory, law enforcement should also make efforts to "target harden" vulnerable landscape features, such as enhancing security and surveillance to detect remote clandestine infrastructure, such as ports and airstrips (e.g., Cohen & Felson, 1979; Farrington & Welsh, 2002; Felson, 1995; Lee, 2010). These techniques should importantly be coupled with community outreach efforts by governments to alert citizens to these changes in order to reduce fear and increase trust between the public and police, and to head off traffickers before they establish their activities in a new area. Given the significant amounts of corruption in some countries and regions in this study, this may approach may likely be met with significant challenges.

7. Conclusions

This study empirically investigated the impact of interdiction on the spatial–temporal adaptations of cocaine trafficking activities through Central America, which are strongly influenced by the attractiveness of landscape features. Our findings extend the prior work of criminologists (e.g., Farrell, 1998; Keh & Farrell, 1997; Tilley et al., 2015; Sampson & Raudenbush, 1999; Stucky & Ottensmann, 2009) and made several novel cross-disciplinary contributions. First, the study unites criminologists' interest in spatial dynamics of crime and law enforcement with geographers' interests in the spatiality of illicitness. To-date, these literatures have been largely siloed, with underexplored connections given shared interests in spatial and temporal aspects of criminal activities and law enforcement responses. Second, our findings advance knowledge of the spatial aspects and consequences of the enforcement side of drug policy, which has been identified as a significantly under-researched area (Caulkins, 2017). Specifically, our analysis shows how various landscape features could become relatively more vulnerable or less enticing to narco-trafficking over time as law enforcement agencies move to seize greater quantities of cocaine. This represents a productive shift in landscape suitability thinking toward logistical rather than productive uses (Tellman et al., 2020).

These unique theoretical and methodological contributions can help researchers and law enforcement better understand the landscape factors underlying traffickers' activities in moving cocaine across large landmasses. Since interdiction resources are limited relative to the overall amount of trafficking activity, knowing which landscape features are viewed as suitable by traffickers can in the short-term guide interdiction deployment strategies, and in the longer term build strategies to mitigate associated harms from trafficking where they are most likely. Our findings also highlight the spatial adaptability of cocaine trafficking and suggest that complementary ex-situ methods (e.g., harm reduction in consumption markets) are likely necessary to curtail the worst effects of the global cocaine trade rather than simply more supply-side interdiction.

Declaration of Competing Interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the members of JIATF-S and in particular Andrew Ajamian (Chief, Strategic Initiatives Group) for their input and advice regarding elements of this manuscript. The authors are also grateful to the constructive comments of two anonymous reviewers which substantially improved the manuscript. This research was supported by the National Science Foundation EAGER ISN #1837698 and D-ISN #2039975.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2022.104359.

References

Allen, C. M. (2005). *2005*. An Industrial Geography of Cocaine. New York: Routledge.
Avalos, H.S. (2019, January 7). GameChangers 2018: Threatened by Inquiries, Central American Elites Strike Back. Insight Crime: Investigation and Analysis of Organized Crime. Accessed via: https://www.insightcrime.org/news/analysis/gamechangers-2018-central-america/.
Ballvé, T. (2012). Everyday state formation: Territory, decentralization, and the narco landgrab in Colombia. *Environment and Planning D: Society and Space, 30*(4), 603–622.
Ballvé, T. (2019). Narco-frontiers: A spatial framework for drug-fuelled accumulation. *Journal of Agrarian Change, 19*(2), 211–224.
Blomley, N. (2003). From what?'to 'so what': Law and geography in retrospect. *Law and Geography, 5*, 17–33.
Bossler, A. M., & Holt, T. J. (2009). On-line activities, guardianship, and malware infection: An examination of routine activities theory. *International Journal of Cyber Criminology, 3*(1), 400–420.
Bosworth, J. (2010). Honduras: Organized crime gaining amid political crisis. In *for Scholars. Working Paper Series on Organized Crime in Central America*. Woodrow Wilson International Center. http://stage-wilson.p2technology.com/sites/default/files/Bosworth.FIN.pdf.
Braga, A. A. (2001). The effects of hot spots policing on crime. *The Annals of the American Academy of Political and Social Science, 578*, 104–125.
Bright, E. A., & Coleman, P. R. (2001). LandScan 2000. *Oak Ridge National Laboratory*. Retrieved from: landscan.ornl.gov/downloads/2000.
Bunck, J. M., & Fowler, M. R. (2012). *Bribes, Bullets, and Intimidation: Drug Trafficking and the Law in Central America*. University Park, PA: The Pennsylvania State University Press.
Caulkins, J. P. (2017). Improving research on drug law enforcement. *International Journal of Drug Policy, 41*, 158–159.
Cohen, L. E., & Felson, M. (1979). Social change and crime rate trends: A routine activity approach. *American Sociological Review, 44*, 588–608.
Dávila, A., McSweeney, K., Magliocca, N.R., Rueda, X. (in review). Spatializing illicit global commodity chains. *Area*.
Devine, J. (2014). Counterinsurgency ecotourism in guatemala's maya biosphere reserve', Environment and Planning D: Society and Space. *Pion Limited, 32*(6), 984–1001. https://doi.org/10.1068/d13043p
Devine, J. A., Wrathall, D., Currit, N., Tellman, B., & Langarica, Y. R. (2018). Narco-Cattle Ranching in Political Forests. *Antipode*. https://doi.org/10.1111/anti.12469
Drawve, G., Thomas, S. A., & Walker, J. T. (2014). The likelihood of arrest: A routine activity theory approach. *American Journal of Criminal Justice, 39*(3), 450–470.
Dudley, S. S. (2010). Drug trafficking organizations in Central America: Transportistas, Mexican cartels and maras. *Shar. Responsib.*, 9.
Duxbury, S. W., & Haynie, D. L. (2019). Criminal network security: An agent-based approach to evaluating network resilience. *Criminology, 57*(2), 314–342.
Eck, J. E., & Weisburd, D. L. (1995). *Crime and place: Crime prevention studies*. Monsey, NY: Criminal Justice Press.
Enders, W. (1995). *Applied Econometric Time Series*. New York: John Wiley & Sons Inc.
Faller, C. S. (2019). *Posture statement of Admiral Craig S. Faller, Commander, United States Southern Command*. Washington, DC: Senate Armed Services Committee 19 pages. Online.
Farrell, G. (1998). Routine activity and Drug Trafficking: The Case of the Netherlands. *International Journal of Drug Policy, 9*, 21–32.
Farrington, David and Brandon Welsh. (2002). Effects of improved street lighting on crime: a systematic review. Home Office Research Study 251, available at https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.456.7395&rep=rep1&type=pdf.
Felson, M. (1995). Those who discourage crime. *Crime and place, 4*, 53–66.
Felson, M., & Eckert, M. (2016). *Crime and everyday life*. Los Angeles, CA: Sage.
Finch, W. H., Bolin, J. E., & Kelley, K. (2019). *Multilevel modeling using R*. Chapman and Hall/CRC.
Fotheringham, A. S., Brunsdon, C., & Charlton, M. (2000). *Quantitative Geography: Perspectives on Spatial Data Analysis*. Thousand Oaks, CA: Sage.
GAO (US Government Accountability Office). (2017). *Counternarcotics: Overview of U.S. efforts in the Western hemisphere* (US Government Accountability Office, Washington, DC), GAO-18-10.
Gelman, A. (2005). Analysis of variance - Why it is more important than ever. *Annals of Statistics, 33*, 1–31.
Global Administrative Areas (2018). *GADM database of global administrative areas* [Data set]. Retrieved from: gadm.org/download_world.html.
Gore, M. L., et al. (2019). Transnational environmental crime threatens sustainable development. *Nature Sustainability*, 1–3. https://doi.org/10.1038/s41893-019-0363-6
Groff, E. R. (2007). Simulation for Theory Testing and Experimentation: An Example Using Routine Activity Theory and Street Robbery. *Journal of Quantitative Criminology, 23*(2), 75–103.
Groff, E. R. (2008). Adding the temporal and spatial aspects of routine activities: A further test of routine activity theory. *Security Journal, 21*(1), 95–116.
Guerette, R. T., & Bowers, K. J. (2009). Assessing the extent of crime displacement and diffusion of benefits: A review of situational crime prevention evaluations. *Criminology, 47*(4), 1331–1368.
Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., et al. (2013). High-resolution global maps of 21st-century forest cover change. *Science, 342*(6160), 850–853.
Holt, T. J., Bossler, A. M., Malinski, R., & May, D. C. (2016). Identifying predictors of unwanted online sexual conversations among youth using a low self-control and routine activity framework. *Journal of Contemporary Criminal Justice, 32*(2), 108–128.
International Development Research Center (IDRC). (2016). Honduras Elites and Organized Crime. Accessed via: https://www.insightcrime.org/images/PDFs/2016/Honduras_Elites_Organized_Crime.pdf.
Keefe, P. R. (2013). The geography of badness: Mapping the hubs of the illicit global economy. In *Convergence: Illicit networks and national security in the age of globalization*. Michael Miklaucic and Jacqueline Brewer, Eds. National Defense University. Institute for National Strategic Studies, Center for Complex Operations (U.S. Army), 97-110.
Keh, D., & Farrell, G. (1997). Trafficking Drugs in the Global Village. *Transnational Organized Crime, 3*(2), 90–110.
Kelly, J.F. "Statement of General John F. Kelly, United States Marine Corps (Ret) Former Combatant Commander, United States Southern Command (USSOUTHCOM) before the Senate Committee on Homeland Security and Governmental Affairs," 2016, p. April 13. Available online: https://www.hsgac.senate.gov/imo/media/doc/Testimony-Kelly-2016-04-131.pdf.
LaGrange, T. C. (1999). The impact of neighborhoods, schools, and malls on the spatial distribution of property damage. *Journal of Research in Crime and Delinquency, 36*, 393–422.
Lee, D. (2010). Understanding and applying situational crime prevention strategies. *Criminal Justice Policy Review., 21*(3), 263–268.
Leukfeldt, E. R., & Yar, M. (2016). Applying routine activity theory to cybercrime: A theoretical and empirical analysis. *Deviant Behavior, 37*(3), 263–280.
Magliocca, N., McSweeney, K., Sesnie, S. E., Tellman, E., Devine, J. A., Nielsen, E. A., et al. (2019). Modeling cocaine traffickers and counterdrug interdiction forces as a complex adaptive system. In *Proceedings of the National Academy of Sciences (PNAS)*. https://doi.org/10.1073/pnas.1812459116
Magliocca, N.R., Torres, A., Margulies, J.D., Carter, N.H., Gore, M., Arroyo-Quiroz, I., Curtin, K.M., Easter, T.S., Hübschle, A., Massé, F., McSweeney, K., Rege, A., Tellman, E. (in press). Comparative Analysis of Illicit Supply Network Structure and Operations: Cocaine, Wildlife, and Sand. *Journal of Illicit Economies and Development*.
Magurran, A. E. (1988). *Ecological Diversity and its Measurement*. Princeton, NJ: Princeton University Press.
McCord, E. S., Ratcliffe, J. H., Marie Garcia, R., & Taylor, R. B. (2007). Nonresidential attractors and generators elevate perceived neighborhood crime and incivilities. *Journal of Research in Crime and Delinquency, 44*, 295–320.
McSweeney, K. (2020). Reliable drug war data: The Consolidated Counterdrug Database and cocaine interdiction in the "Transit Zone". *International Journal of Drug Policy*. https://doi.org/10.1016/j.drugpo.2020.102719
McSweeney, K., et al. (2014). Conservation. Drug policy as conservation policy: Narcodeforestation. *Science, 343*, 489–490.
McSweeney, K., Richani, N., Pearson, Z., Devine, J., & Wrathall, D. J. (2017). Why do narcos invest in rural land? *Journal of Latin American Geography, 16*, 3–29.
McSweeney, K., Wrathall, D. J., Nielsen, E. A., & Pearson, Z. (2018). Grounding traffic: The cocaine commodity chain and land grabbing in eastern Honduras. *Geoforum, 95*, 122–132.
Messner, S. F., & Tardiff, K. (1985). The social ecology of urban homicide: An application of the "routine activity" approach. *Criminology, 23*, 241–267.
Netherlands Enterprise Agency (NEA). (2018). The seaports of Central America: developments, opportunities, and background info 2017. Embassy of the Netherlands in Costa Rica. Publication No RVO-050-1801/RP-INT.
O'brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality & Quantity*, 41(5), 673-690.
Office of National Drug Control Policy (ONDCP), "Cocaine," 2018. [Online]. Available: https://www.whitehouse.gov/ondcp/key-issues/cocaine/. [Accessed: 20-Feb-2018].
Office of the Inspectors General (OIG), "DHS Drug Interdiction efforts need improvement," Washington, D.C., 2016.
Office of the Inspectors General (OIG), (2019). Review of U.S. Coast Guard's fiscal year 2018 Drug Control Performance Summary Report. Washington, DC: Office of the Inspector General, Department of Homeland Security. [Report, OIG-19-27, 5 pages].

Osgood, D.W. and Chambers, J.M. (2000). Social disorganization outside the metropolis: An analysis of rural youth violence. *Criminology*, 38:81–115.
Openshaw, S. (1984). Ecological Fallacies and the Analysis of Areal Census Data. *Environment and Planning A, 16*(1), 17–31. https://doi.org/10.1068/A160017
OpenStreetMap contributors (2019). *Planet dump* (Data file from 2019-06-06) [Data set]. Retrieved from https://planet.openstreetmap.org.
Osgood, D. W., & Chambers, J. M. (2000). Social disorganization outside the metropolis: An analysis of rural youth violence. *Criminology, 38*(1), 81–116.
Podesta, F. (2002). Recent developments in quantitative comparative methodology: The case of pooled time series cross-section analysis. *DSS Papers Soc*, 2–3.
PRISMA (2014). *Informe PRISMA: pueblos indígenas y comunidades rurales defendiendo derechos territoriales. Estudios de caso sobre experiencias de prevención y defensa ante narcotráfico y el crimen organizado en Mesoamérica*. Pasaje Sagrado Corazón, No. 821, Col. Escalón, San Salvador 56 p.
Reynald, D. M. (2016). Guarding against crime: Measuring guardianship within routine activity theory. *Routledge*.
Reuter, P., Pollack, H. A., & Pardo, B. (2016). If tougher enforcement cannot reliably raise drug prices, what are appropriate goals and metrics? In J. Collins (Ed.), *After the Drug Wars* (pp. 51–58). London, UK: LSE IDEAS.
Rice, K. J., & Smith, W. R. (2002). Socioecological models of automotive theft: Integrating routine activity and social disorganization approaches. *Journal of Research in Crime and Delinquency, 39*, 304–336.
Roncek, D. W., & Maier, P. (1991). Bars, blocks, and crimes revisited: Linking the theory of routine activity to the empiricism of "hot spots". *Criminology, 29*, 725–753.
Roncek, D. W., & Pravatiner, M. A. (1989). Additional evidence that taverns enhance nearby crime. *Sociology and Social Research, 73*, 185–188.
Rosenzweig, M. L. (1995). *Species Diversity in Space and Time*. New York, NY: Cambridge University Press.
Sampson, R. J., & Raudenbush, S. W. (1999). Systemic social observation of public spaces: A new look at disorder in urban neighborhoods. *American Journal of Sociology, 105*, 603–651.
Sesnie, S., Tellman, B., Wrathall, D., McSweeney, K., Nielsen, E., Bennesaiah, K., et al. (2017). A spatio-temporal analysis of forest cover loss related to cocaine trafficking in Central America. *Environmental Research Letters, 12*. https://doi.org/10.1088/1748-9326/aa6fff
Sherman, L. W., Gartin, P. R., & Buerger, M. E. (1989). Hot spots of predatory crime: Routine activities and the criminology of place. *Criminology, 27*, 27–56.
Soudijn, M., & Reuter, P. (2016). Cash and carry: The high cost of currency smuggling in the drug trade. Crime. *Law and Social Change, 66*(3), 271–290.
Steenbeek, W., & Weisburd, D. L. (2016). Where the action is in crime? An examination of variability of crime across different spatial units in The Hague, 2001–2009. *Journal of Quantitative Criminology, 32*, 449–469.
Stucky, T. D., & Ottensmann, J. R. (2009). Land use and violent crime. *Criminology, 47*(4), 1223–1264.
Summers, L., & Johnson, S. D. (2017). Does the configuration of the street network influence where outdoor serious violence takes place? Using space syntax to test crime pattern theory. *Journal of Quantitative Criminology, 33*(2), 397–420.
Tellman, B., Magliocca, N. R., Turner, B. L., & Verburg, P. H. (2020a). Understanding the role of illicit transactions in land-change dynamics. *Nature Sustainability, 3*, 175–181.
Tellman, E., Sesnie, S., Magliocca, N. R., Nielsen, E., Devine, J., McSweeney, K., et al. (2020b). Illicit Drivers of Land Use Change: Narcotrafficking and Forest Loss in Central. *Global Environmental Change*.
Tilley, Nick, Graham Farrell, and Ronald Clarke. (2015). "Target Suitability and the Crime Drop," in *The Criminal Act: The Role and Influence of Routine Activity Theory* 1st edition. Nick Tilley, G. Farrell, R. Clarke, and J. Maguire (eds), pp. 59-76.
Tseloni, A., Wittebrood, K., Farrell, G., & Pease, K. (2004). Burglary victimization in England and Wales, the United States, and the Netherlands: A Cross-National Comparative Test of Routine activity and Lifestyle Theories. *British Journal of Criminology, 44*(1), 66–91.
United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) and International Union for Conservation of Nature (IUCN). (2020). Protected planet: The world database on protected areas [Data set]. Retrieved from: www.protectedplanet.net.
UNODC. (2012). Transnational Organized Crime in Central America and the Caribbean: a Threat Assessment. Vienna: United Nations Office on Drugs and Crime.
United States Department of Justice (DOJ), "Federal Government Conducts Unprecedented Seizure of Massive Cargo Ship After Finding Almost 20 Tons of Cocaine on Board." U.S. Attorney's Office, Eastern District of Pennsylvania. Philadelphia, 2019. Online: https://www.justice.gov/usao-edpa/pr/federal-government-conducts-unprecedented-seizure-massive-cargo-ship-after-finding.
Venables, W. N., & Ripley, B. D. (2013). *Modern applied statistics with S-PLUS*. Springer Science & Business Media.
Wang, F. (2007). Job access in disadvantaged neighborhoods in Cleveland, 1980-2000: Implications for spatial mismatch and association with crime patterns. Cityscape: *A Journal of Policy Development and Research*, 9:95–121.
Weisburd, D., Bernasco, W., & Bruinsma, G. (2009). *Putting crime in its place: Units ofanalysis in spatial crime research*. New York: Springer.
Weisburd, D., Wyckoff, L. A., Ready, J., Eck, J. E., Hinkle, J., & Gajewski, F. (2004). *Does Crime Just Move Around the Corner? A Study of Displacement and Diffusion in Jersey City*. Department of Justice: NJ. U.S. Available at: https://www.ojp.gov/pdffiles1/nij/grants/211679.pdf.
Williams, M. (2015). Guardians upon high: An application of routine activity theory to online identity theft in Europe at the country and individual level. *British Journal of Criminology, 56*(1), 21–48.
World Port Source (WPS). (2020). Countries with ports in Central America. Accessed via http://www.worldportsource.com/ports/region.5.php.
Wrathall, D. J., Devine, J., Aguilar Gonzalez, B., Benessaiah, K., Tellman, E., Sesnie, S., et al. (2020). The impacts of cocaine-trafficking on conservation governance in Central America. *Global Environmental Change*.
de Córdoba, J. (2021). "Honduran President Hernández Implicated in Drug Trade". Wall Street Journal, 10 January, 2021. URL: https://www.wsj.com/articles/honduran-president-hernandez-implicated-in-drug-trade-11610254811.