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Spatial and spatiotemporal clustering methods for detecting elephant poaching hotspots

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ABSTRACT

Spatial and spatiotemporal cluster methods are used for a wide range of applications including the study of criminal activities, but have never been compared for studying a specific form of crime, i.e. wildlife poaching. We aimed to identify elephant poaching hotspots by analyzing the differences in clusters of poached elephants in the Tsavo ecosystem (Kenya) that emerged from different cluster detection methods. Reports of elephant poaching in the Tsavo ecosystem were obtained for 2002–2012 from the Kenya Wildlife Service. The study area was divided into 34 blocks for analysis. Two spatial- and two spatiotemporal clustering methods were applied to the data. The predictive accuracy of the spatial methods in defining hotspots was assessed using the prediction accuracy index (PAI), which was then modified (MPAI) for measuring the predictive accuracy of the spatiotemporal methods. The results from the spatial methods indicated eight consistent poaching blocks, with Kulldorff's spatial scan statistic having a slightly higher PAI value than the flexible scan statistic (2.39 vs 2.12). The spatiotemporal clustering methods revealed four consistent poaching blocks. The MPAI value was higher for the spatiotemporal scan statistic than the spatiotemporal permutation scan statistic (1.46 vs 0.97). The results demonstrated that although the hotspot predictions varied for the different methods, three blocks were consistently identified as poaching hotspots. Our findings may assist wildlife departments such as the Kenyan Wildlife Service to allocate their financial and human resources as effectively as possible in combating poaching. Further research is needed to examine the environmental and human factors contributing to the patterns that have been observed in elephant poaching.

1. Introduction

Cluster analysis aids in identifying the presence of spatial and temporal patterns (Quick and Law, 2013). It can discern areas or periods of high occurrence (hotspots) of a specific feature from other areas or periods with a more random occurrence. Many methods for testing the presence of clusters in spatial point features have been defined and they can be broadly divided into global and local clustering methods (Chiu et al., 2008). In global clustering methods, the average tendency (a typical value for a probability distribution, e.g. mean or median) in a dataset is measured to test the null hypothesis of spatial randomness over the whole study area. However, the specific location or significance of individual clusters is not specified by global methods (Burra et al., 2002; Chakravorty, 1995; Quick and Law, 2013). In contrast, local clustering methods identify the location of individual clusters by processing subsets of global data; local clustering methods recognize neighboring regions that show exceedingly high or low occurrences relative to the null hypothesis of spatial randomness (Anselin, 1995; Anselin et al., 2000; Kulldorff et al., 2003; Quick and Law, 2013). Local clustering can be classified in three groups: temporal clustering, spatial clustering, or spatiotemporal clustering (Tango, 2010). Temporal clustering investigates whether cases show a tendency to be placed close to each other in time (Tango, 2010). Spatial clustering investigates if the occurrence of a specific feature is particularly high in some geographical areas, irrespective of when it occurred during the study period. Spatiotemporal clustering investigates whether events that are close in space are also close in time (Tango, 2010).

Cluster analysis used in epidemiology (Hanson and Wieczorek, 2002; Kulldorff, 1997; Torabi and Rosychuk, 2011) and has been

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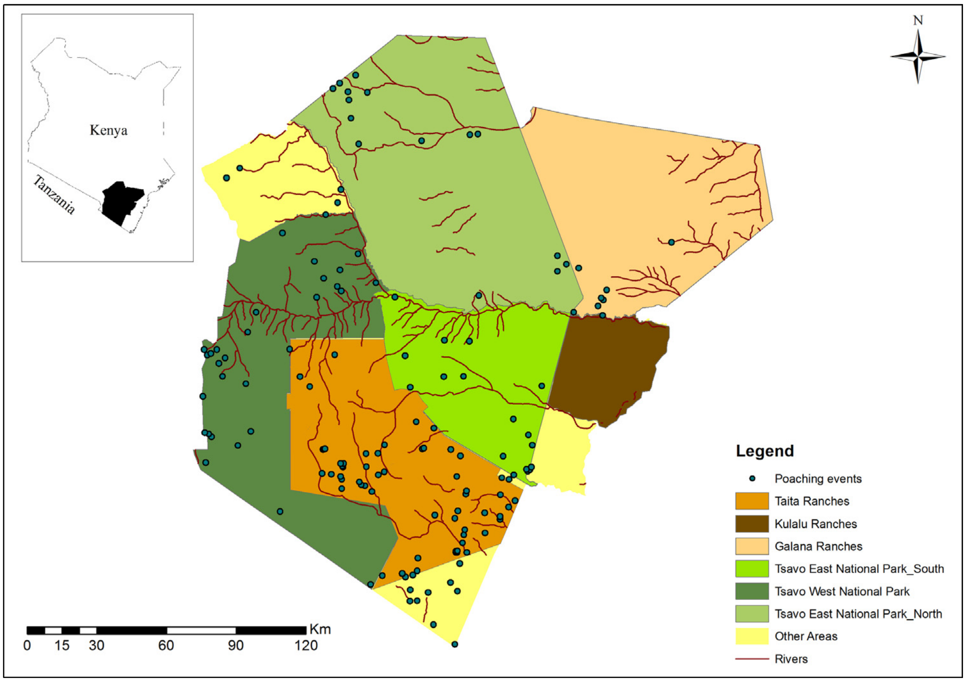

Fig. 1. Location of the Tsavo ecosystem in south-eastern Kenya, showing the locations where elephants are being poached and the types of land use.

applied to crime data to assist decision-making on where and when to address potential crime clusters in future, e.g. for drug offenses (Quick and Law, 2013) or city violence and property crimes (Uittenbogaard and Ceccato, 2012). However, few studies exist that aimed at detecting spatial and spatiotemporal patterns in the specific criminal act of wildlife poaching. One example is Haines et al. (2012) who studied white-tailed deer poaching activity in Fayette County, Iowa, USA, in terms of temporal, spatial, and environmental patterns. They used logistic regression models and produced poaching activity hotspots map.

Although elephant populations are declining across their habitat range in Africa and poaching is a significant source of mortality, little attention has been paid to predicting poaching hotspots. Analysis of data related to poaching is important for wildlife conservation. Based on elephant mortality data collected between 1989 and 2005 Kyale et al. (2011) identified spatial patterns of elephant mortality, which is largely due to poaching, in Tsavo East National Park in Kenya. They used kernel density analyses and found that the patterns were clustered, with poaching being more intensive in the northern and central areas of the park. Maingi et al. (2012) studied spatial patterns of elephant poaching separately for wet and dry season for the period between January 1990 and December 2009 in south-eastern Kenya. They used kernel density analyses and concluded that poaching was more common in the dry season when the elephants aggregate along permanent rivers. However, their analysis merely separated the two seasons and assessed hotspots for each, but did not address both space and time in a single model. In fact, poaching hotspots have never been mapped using spatiotemporal methods and the differences in hotspots that emerge from various clustering methods have not been evaluated.

We therefore set out to identify elephant poaching hotspots by analyzing the differences in emerging clusters of poached elephants in the Tsavo ecosystem. We used different cluster detection methods on data covering a continuous period of ten years. We selected four common clustering methods (two spatial, two spatiotemporal) for this purpose. Our study aimed to answer the following five questions: (1) Where are the consistent elephant poaching hotspots as determined by various spatial and spatiotemporal clustering methods? (2) What are the differences between the emerging clusters obtained by the different spatial clustering methods? (3) Do spatial clustering methods differ in their ability to predict where hotspots may occur? (4) What are the differences between the emerging clusters obtained by different spatiotemporal clustering methods? (5) Do the spatiotemporal clustering methods differ in their ability to predict where and when hotspots may occur?

2. Materials and methods

2.1. Study area

The Tsavo ecosystem covers an area of about 38,128 km^2 in south-east Kenya (Fig. 1). The ecosystem lies between 2–4° S, and 37.5–39.5° E (Ngene, 2013). It has a population of about 11,000 elephants (Kyale et al., 2014), and the highest reported poaching of elephants, in Kenya (Maingi et al., 2012). The anti-poaching activities in the Tsavo ecosystem are challenged by inadequate resources (human and financial), and the extensive area covered (Maingi et al., 2012). Various rivers traverse the ecosystem, including the Galana, Voi, Tiva, Tsavo and Athirivers (Maingi et al., 2012). Our study area comprised the Tsavo East national park north, Tsavo East national park south, and Tsavo West national parks, with the remainder covered by private ranches (Fig. 1). The climate of the area is semi-arid, with the long rainy season occurring between March and May, and the short rainy season in November and December. Mean annual rainfall varies locally between 250 and 500 mm (Maingi et al., 2012). Vegetation in the Tsavo ecosystem is dominated by Commiphora savanna (Maingi et al., 2012).

2.2. Elephant data

The poaching and population data on elephants used for this study were obtained from the Kenya Wildlife Service (KWS). The poaching data were collected from aerial patrols and daily ground patrols carried out by KWS through monitoring illegal killing of elephants (MIKE) program. Regular patrols and extensive coverage of monitored sites is essential to collect comprehensive data for