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A decade of poaching trends and law enforcement in Kakum Conservation Area, Ghana

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Protected areas play a critical role in biodiversity conservation, but they are increasingly threatened by poaching. This study provides the first long-term analysis of poaching trends and law enforcement effectiveness in Kakum Conservation Area, Ghana's most visited protected area. Drawing on ranger patrol data collected between 2012 and 2021, we analysed trends and seasonal variations in poaching indicators and enforcement effort and the relationship between enforcement effort and poaching activity. Twelve indicators of poaching were identified, with poachers' paths, gunshots, footprints, snares and gin traps and empty cartridges being the most frequent. Trend analysis revealed a general decline in most indicators, including snares, cartridges, footprints and poachers' camps, suggesting that consistent patrol of defined areas of the Park contributed to reduced poaching pressure. However, the rise in poachers' paths points to hunters adapting their strategies to avoid detection. Seasonal analysis showed no significant difference in most indicators between the open and closed hunting seasons, highlighting gaps in compliance with Ghana's wildlife regulations. Patrol effort, measured as Patrol Man-Days, was relatively high and consistent between 2012 and 2016 but declined sharply after 2017, reaching its lowest levels between 2019 and 2021. Weak positive correlations between Patrol Man-Days and most poaching indicators suggest that more patrols improved detection but did not necessarily reduce incidents in the short term. The decline in patrol effort during the COVID-19 pandemic illustrates how enforcement is vulnerable to resource constraints and external shocks. Although the recorded poaching decreased during periods of reduced patrols, illegal activity remains ongoing and responsive to enforcement conditions.

Conservation implications: Sustained law enforcement probably reduced poaching in Kakum Conservation Area, but illegal activities persist and adapt. Strengthening community participation, ensuring consistent patrol funding across the entire reserve, and using technology can enhance effectiveness. Adaptive management and stronger regulation are essential to sustain biodiversity conservation and reduce wildlife exploitation in protected areas.

Keywords: poaching; law enforcement; Kakum Conservation Area; Ghana; Patrol Man-Days (PMD); protected areas; trend analysis.

Introduction

Protected areas (PAs) are widely recognised as critical refuges for wildlife, and well-managed PAs contribute significantly to the maintenance and recovery of wildlife populations. Protected areas also provide evidence of historical changes, especially in land use, land changes and resource utilisation within an area over a period (Glover 2020). Various management regimes that have contributed to the protection and conservation of these areas are readily apparent, thereby defining their role over and above biodiversity protection, in ecotourism and heritage.

The various functions and services provided by PAs are not limited to the provision of support for local livelihoods, protection of soil cover and provision of food, goods and income from the sale of forest products, as well as inputs for agriculture, employment and climate change mitigation (Balvanera et al. 2006; Haines-Young & Potschin 2010; Le Noë et al. 2021; Zedler & Kercher 2005). The economic valuation of resources within PAs is worth mentioning to draw more attention to the importance of PAs. The economy of many countries is heavily dependent on the income generated from ecotourism. For example, according to the World Tourism Organisation (2014), more than half of the total number of global wildlife tourists visit Africa each year. This volume translates into generating an income of about

US$29 billion, contributing to about 4% of the continent's gross domestic product (GDP) and creating employment for about 3.6 million people (Lindsey et al. 2020). However, these significant economic benefits are increasingly under threat from poaching. By reducing wildlife populations and degrading the integrity of PAs, poaching reduces their attractiveness for ecotourism, affects the livelihoods of wildlife-dependent communities and weakens both local and national economies.

In Ghana, ecotourism's contribution to the employment industry stands at about 5.3% of the country's total employment. The contribution of this sector to the country's GDP, for example, in 2018, amounted to US$996 million (Forestry Commission 2021). Community ecotourism offers readily available employment to residents of communities and puts such communities on the world map by giving them the needed visibility. Despite the importance of PAs in the conservation and preservation of biodiversity, several threats, particularly from human population growth and unsustainable exploitation, continually undermine the integrity of these areas and eventually affect wildlife populations, ecosystem stability and long-term conservation efforts and degrade ecotourism and job creation opportunities (Obour et al. 2016; World Tourism Organisation 2014).

Poaching and resource extraction are widely recognised as among the most significant threats to PAs globally (Musyoki et al. 2012). Although poaching is defined in various ways, in the context of this study, it refers to the illegal hunting, capturing or killing of wildlife in violation of ownership rights or wildlife protection laws, often for subsistence or commercial gain, as reflected by ranger-recorded indicators such as snares and gin traps, gunshots, spent cartridges, footprints, poachers' paths and temporary poachers' camps and constitutes a major threat to biodiversity (Jayakrishnan 2023). The drivers of poaching may be described as a complex interplay of cultural, socio-economic and institutional factors. These factors may include human–wildlife conflict, preference and demand for bushmeat and wildlife products, poverty, inadequate enforcement capacity, gaps in community engagement and illegal wildlife trade. Diffenbaugh et al. (2020) established a relationship between poaching intensity and human population in a poverty-driven economy. Communities associated with a high poverty rate are more likely to engage in more poaching activities.

Wildlife poaching and crime are now considered global threats to conservation, drawing significant attention from governments all over the world (Ashokumar 2023; Dalpane & Baideldinova 2022). Despite global awareness of this cancer, wildlife poaching as a threat to conservation has equally been quite challenging to deal with by global authorities (Duffy 2022; Van Uhm 2016). The reason has been the lucrative nature of this business on the illegal market. Income generated from legal wildlife trade amounts to approximately US$350b, whereas amounts realised through poaching activities reach up to estimates of US$20b annually (Korenblik, Leggett & Shadbolt 2016; Ontar 2024; Petrossian, Pires & Van Uhm 2016). Gao and Clark (2014) reported that the market price of 1 kg of elephant ivory in China in 2013 was equivalent to US$5,700.00. In Ghana, for instance, the price of bushmeat varies across species, with mean prices reaching up to US$7.0 per kilogram (Sackey et al. 2023). This value is about 3.8 times the daily minimum wage of Ghanaians. Illegal hunters equally match the demand and value of these wildlife products, amid efforts put in place to deter people from engaging in poaching activities. A record 100 elephants (including pregnant females and calves) have reportedly been killed in barely a quarter of the year in different parts of sub-Saharan Africa (Messenger 2014; Quarterman 2013). There has been a shift from the use of simple tools in poaching activities in some of the hotspot poaching areas to sophisticated machinery in the extraction process by some poachers, to continuously enhance their selfish gains. (Kamminga et al. 2018; Kashyap et al. 2024; Schauer 2015). In an attempt to avoid detection from the noise made by some of the equipment used in hunting wild animals, some illegal hunters have resorted to techniques such as poisoning of water sources used by the animals for drinking purposes to silently kill the animals (Eller 2014; Thornycroft & Laing 2013). The conflict between poachers and law enforcement agencies has at times resulted in violent encounters, including fatalities on both sides (Moreto 2019). In another dimension, activities and proceeds of poaching have been linked to acts of terrorism (Haenlein, Maguire & Somerville 2016; Saru 2016).

Ghana has about 300 PAs, of which 21 are Wildlife Protected Areas. The Wildlife Protected Areas comprise seven National Parks, five coastal Ramsar sites, six Resource Reserves, two Wildlife Sanctuaries and one Strict Nature Reserve (IUCN/PACO 2010). Kakum National Park (KNP) is the second most visited tourist site in Ghana overall, but the most visited among the country's PAs (Ghana Tourism Authority 2024). The Kakum Conservation Area (KCA) was legally gazetted as a National Park and Resource Reserve in 1992 under the Wildlife Reserves Regulations (LI 1525) (IUCN/PACO 2010). Before this move, the KNP had a Forest Reserve status, which accorded it some protection from unlawful entry and use. However, upgrading it to the current status meant higher restrictions on its utilisation by local communities.

As expected, preventing local communities from freely using resources that they had lived on all their life was met with some opposition. This restriction required enhanced law enforcement by the Wildlife Division, which is mandated to ensure the strict protection of wildlife in the park. This enhancement is increasingly necessary as wild animals are vulnerable because they easily move out of their 'protection zone' into places where they may be easily targeted and killed (Amoah & Wiafe 2012). Several anthropogenic activities have been identified in and around the KCA. These activities could serve as threats to the management and conservation of the KCA.

Among such activities are farming, poaching and illegal hunting or harvesting of forest and wildlife resources, encroachment and settlement expansion (Binlinla, Voinov & Oduro 2014).

The reported poaching levels in the KCA are not as comprehensive in the literature as reported from other areas. Wiafe (2018) reported on some 69 wild animals harvested illegally from the KNP within a period of 12 months from November 2012 to November 2013, comprising 12 species across 13 locations by 17 poachers. Among the species poached were primates such as Lowe's monkey *Cercopithecus lowei* and the olive colobus Procolobus verus, both listed as Vulnerable on the International Union for Conservation of Nature (IUCN) Red List, as well as the spot-nosed monkey C. petaurista and the West African potto *Perodicticus potto*, which are classified as Near Threatened.

Since 1992, when KNP was gazetted and given strict protection against poaching, considerable effort has been invested in enforcing the law against poaching (Wiafe & Amoah 2012). In addition, the Wildlife Conservation Regulation of 1971 (LI 685) of Ghana prohibits hunting, capturingor destroying wild animals except the greater cane rat *Thryonomys swinderianus* during the period 01 August to 01 December (Adom & Boamah 2020; IUCN/PACO 2010). This period, known as the Closed Season, provides additional protection to wildlife and provides the needed authority to wildlife officials to ensure compliance with the LI. Nevertheless, there is evidence in the marketplaces of bushmeat other than greater cane rats, openly or secretly traded in the closed season (Sackey et al. 2023). The period from 01 December to 01 August constitutes the Open Season, during which licensed hunters are permitted to hunt, capture or kill specified wildlife species. The persistent violations highlight the need for a comprehensive assessment of poaching trends and intensities in PAs such as KCA, in relation to law enforcement efforts.

This study aims to assess the trends and levels of poaching at the KCA. Evaluating the poaching trends and analysing the patterns in poaching incidents, assessing the tools and equipment used in poaching and evaluating enforcement efforts will help provide a better understanding of the threat poaching poses to the ecological integrity of the KCA. We therefore proposed and tested two hypotheses for this study. Firstly, the levels of poaching are reduced in the closed season as compared to the open season. Secondly, the hypothesis states that enforcement efforts influence the levels of poaching in the KCA. Furthermore, data obtained from this study will provide evidence-based insights that can contribute to formulating management practices and strategies to enhance conservation outcomes. A comprehensive understanding of the dynamics of poaching as a threat to conservation actions at the KCA is essential for developing targeted interventions, strengthening enforcement mechanisms and fostering community-based approaches to wildlife protection.

Research methods and design

Study area

The study was carried out in the KNP and Assin Attandanso Resource Reserve (Figure 1), which forms the KCA. The KNP was previously declared in the 1920s as a forest reserve. However, overexploitation of the resources as a result of poor management led to its gazetting as a national park in 1992 under the Wildlife Reserves Regulations (LI 1525) (Hawthorne & Abu-Juam 1995; Kpelle 1993). The KCA has a total of 350 km^2, with the KNP covering an area of *ca*. 210 km^2 and lies between Latitude 5° 19′ 59.9988′ – 5° 39′ 0″ N and Longitude 1° 16′ 59.9988″ – 1° 26′ 60″ W in the Central Region of Ghana. The vegetation of the KNP is a moist semi-deciduous rainforest characterised by a high annual average rainfall of about 1380 mm (Wiafe & Amoah 2012). The park is home to several protected mammals and birds. Notable mammals include the African Elephant (*Loxodonta cyclotis*), Maxwell's Duiker (*Philantomba maxwellii*), Black Duiker (*Cephalophus niger*), Bongo (*Tragelaphus eurycerus*), Lowe's Monkey (*Cercopithecus lowei*), Olive Colobus (*Procolobus verus*) and Black-and-White Colobus (*Colobus vellerosus*). Conspicuous bird species include seven hornbill species, the turacos (Yellow-billed Turaco [*Tauraco macrorhynchus*], Green Turaco, the Great Blue Turaco) and many other bird species. The park is surrounded by 52 communities, including Aboabo, Antwikwaa, Ahomaho, Adiembra, Mfuom, Abrafo and Kuruwa, among others, with an estimated population of 65000 and 70000 people (Kakum National Park n.d.; Mensah 2017). People from these communities are mostly cocoa farmers (Monney, Dakwa & Wiafe 2010). The KNP is the most patronised national park in Ghana, with a record total visitation of 185740 in 2019 (Forestry Commission 2021). This number is arguably because of the presence of a unique Canopy Walkway, which allows visitors an aerial view of the forest.

Data collection

Because of the high faunal diversity of the KCA and its proximity to the surrounding communities, there has always

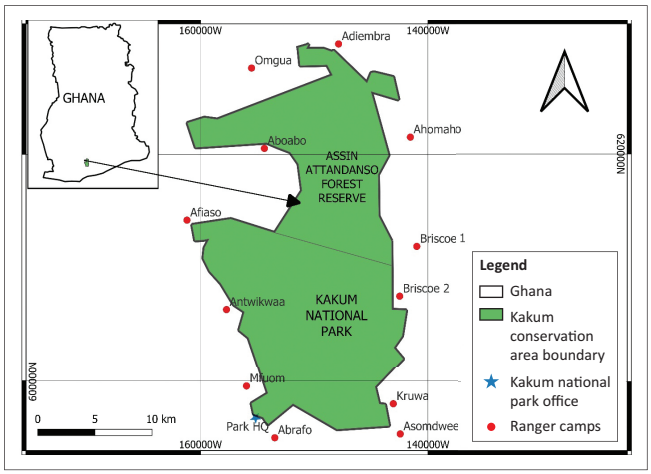


FIGURE 1: Kakum Conservation Area showing the Kakum National Park and the Assin Attandanso Forest Reserve.

been a need for management to institute proper measures in the protection and conservation of resources within the park. As in other PAs in Ghana, patrolling of the park, mostly on foot, is one of the most common methods used in ensuring regular stewardship of its resources. The management of the KCA has resorted to regular monthly patrols on foot in the forests by trained staff of the Wildlife Division of the Forestry Commission of Ghana, popularly known as wildlife protection rangers. This act is to deter any form of illegal entry into the park and poaching activities. During such patrols, data on the presence of poachers and poaching activities are recorded. The poachers encountered are arrested. Poaching activities, including the number of animals harvested or killed, the hunting methods used and the number of poachers involved, are recorded. All information is filed in a quarterly and annual field patrol report managed by the law enforcement unit (Wiafe 2016, 2018).

For this study, data from the quarterly and annual field patrol reports, spanning the period from 2012 to 2021, were obtained from the law enforcement unit of the KCA. These reports contain information on the indicators of poaching activities. Some of the indicators of poaching activities include the presence of empty cartridges, sounds of gunshots, snares and gin traps found, poachers observed or arrested, poaching camps, human footprints other than those of patrolling staff (hereafter referred to as footprints), carbide powder, tree marking, poachers' paths, burning, killed animals found and tree cutting or harvesting. Trends in this study refer to the overall directional change in poaching occurrences in the last decade (2012–2021).

There were gaps in data availability on the indicators of poaching, which were obtained from the law enforcement unit of the KCA. Generally, there was no data collection in the KCA between April 2020 and June 2020, coinciding with the period of the national lockdown because of the coronavirus disease 2019 (COVID-19) pandemic. Data on all indicators of poaching commenced from January 2012, except data on tree marking, poachers' paths and animals found killed, which commenced in January 2013 to December 2021, January 2015 to December 2021 and October 2016 to December 2021, respectively. For this reason, the indicators of poaching used in the trend analysis included the presence of empty cartridges, sounds of gunshots, snares and gin traps found, poachers observed or arrested, poaching camps, footprints, carbide powder and tree cutting or harvesting. Furthermore, data on the Patrol Man-Days (PMD), also known as Effective Patrol Man-Days (EPMD) in other contexts, were also obtained from the quarterly and annual reports for the study period and used as a measure of enforcement effort. In this study, PMD represents the standardised measure of patrol effort, estimated by converting the total patrol hours into 'man-days'. It accounts for both the duration of patrols and the number of personnel involved. That is, PMD = (Total patrol hours/8) x number of patrol staff. The PMD is a standardised metric often used in ranger-based monitoring and conservation enforcement to measure patrol effort.

Data analyses

Data on indicators of poaching were checked for normality, using the Shapiro-Wilk test. As data on the indicators of poaching were not normally distributed ($p < 0.05$), non-parametric statistical tests were used to check for differences in frequencies and means of the indicators of poaching across the different months and years. Abundances of indicators of poaching were represented by frequencies. The Wilcoxon rank-sum test was used to test for differences in the mean abundances of the poaching indicators between the closed and open seasons. The trends in the indicators of poaching were determined by using the 'rtrim-package': Trends and Indices for Monitoring in R, which analyses long-term data using the TRends and Indices for Monitoring (TRIM) models (Pannekoek & Van Strien 2001). The TRIM models are originally designed for estimating trends in species populations, based on annual count data collected over a period. The model is also able to account for missing data based on the estimation of population totals. For this study, the TRIM models were employed to identify trends in the abundance of poaching indicators over time, with a focus on monthly variations. As data are collected from a single site and at different times, the TRIM Model 2, which seeks to determine trends in the data assuming a steady and constant growth at specified time intervals, was used (Bogaart et al. 2020). Data were first checked for sufficiency to run the selected model, after which the model was computed for data that passed this test.

Therefore, the following indicators of poaching successfully pass the sufficiency test and, as such, the models estimated: snares and gin traps, gunshots heard, empty cartridges found, poaching camps, poachers observed or arrested, footprints other than those of the patrolling team and poachers' paths. The *p*-value of the trend, which shows the annual percentage change in the count of the indicators of poaching, is presented as well. Trends in the effectiveness of law enforcement were represented by a circular bar plot. The PMD was used as a measure of the effectiveness of law enforcement for this study. The individual bars in the circular plot represented the monthly PMD. The Kruskal-Wallis (H) test was used to test for differences in the temporal variation in the annual mean PMD across the 10 years, and Dunn's *post hoc* pair-wise test followed a significant H test. The Wilcoxon rank-sum test was used to test for differences in the mean PMD between the closed and open seasons. The relationship between the indicators of poaching and PMD was determined by using Pearson's correlation coefficient (r). Data for both the PMD and the indicators of poaching were log-transformed before the estimation of the r. All statistical analyses were computed at a p-value of 0.05.

Ethical considerations

This study did not involve human participants, animals or animal products. Data were obtained from the existing database at the Law Enforcement Unit of the KCA, which

posed no ethical risks. Therefore, formal ethical approval was not required. However, data sources have been properly acknowledged, and due diligence was observed to uphold academic integrity and environmental responsibility throughout the study.

Results

Composition and abundance of indicators of poaching in the Kakum National Park

A total of 12 different activities were obtained from the monthly field patrol reports from the law enforcement unit of the KCA between 2012 and 2021. These activities were used as indicators of poaching. These include snares and gin traps found, gunshots heard, empty cartridges, poachers' camps, poachers observed or arrested, poachers' paths, carbide powder, footprints other than rangers' footprints, tree cutting or harvesting, tree marking, animals found killed and evidence of burning activities.

The most frequent indicator of poaching observed in the KCA during the 10 years and the frequencies of observation include the presence of poachers' paths (25%), gunshots heard (20%), footprints (16%), snares and gin traps (15%), empty cartridges (11%) and poachers observed or arrested (7%). The least common activities observed include carbide powder, tree markings and burning activities, each of which was less than 1% (Figure 2a).

The proportion of the different indicators of poaching varied among the various years under review. The proportion of empty cartridges ranged between 5.6% and 18.8% of the total abundance of indicators of poaching in a year, following a declining pattern over the years. On the contrary, poachers' paths with an estimated proportion ranging from 0% to 50.5% showed an increasing pattern over the years. The proportion of activities such as gunshots heard and poachers observed or arrested showed an unclear pattern, whereas that of poachers' camps remained relatively stable (Figure 2b).

Temporal trends in the indicators of poaching

The trend analysis of the indicators of poaching in the KCA between the years 2012 and 2021 showed a significant general decline ($p < 0.05$) in five of the seven indicators of poaching. A summary of moderate decreases in the trends was determined for the following indicators: snares and gin traps found, empty cartridges found, number of poaching camps and number of poachers observed or arrested. There was a strong, significant decrease observed in the trend ($p < 0.05$) of the number of footprints observed. The number of gunshots heard showed a significantly stable trend ($p = 0.52$) across the 10-year period, whereas that of the number of poachers' paths observed showed a significantly strong increasing trend ($p < 0.05$) (Figure 3).

Seasonal variation in poaching activities

It is anticipated that there will be differences in the mean number of the various indicators of poaching between the two seasons. This expectation is based on Ghana's seasonal hunting regulations, which prohibit most hunting activities during the closed season. Wilcoxon rank-sum tests showed that there were no significant differences in the mean numbers of the indicators of poaching observed between the closed and open seasons for all recorded activities ($p > 0.05$) but for footprints other than those of the patrolling team ($W = 1065$; $p = 0.01$) (Figure 4). This finding suggests that there were more footprints other than those of the patrolling team observed in the closed season (7.8 ± 0.75 footprints) than in the open season (5.51 ± 0.51 footprints).

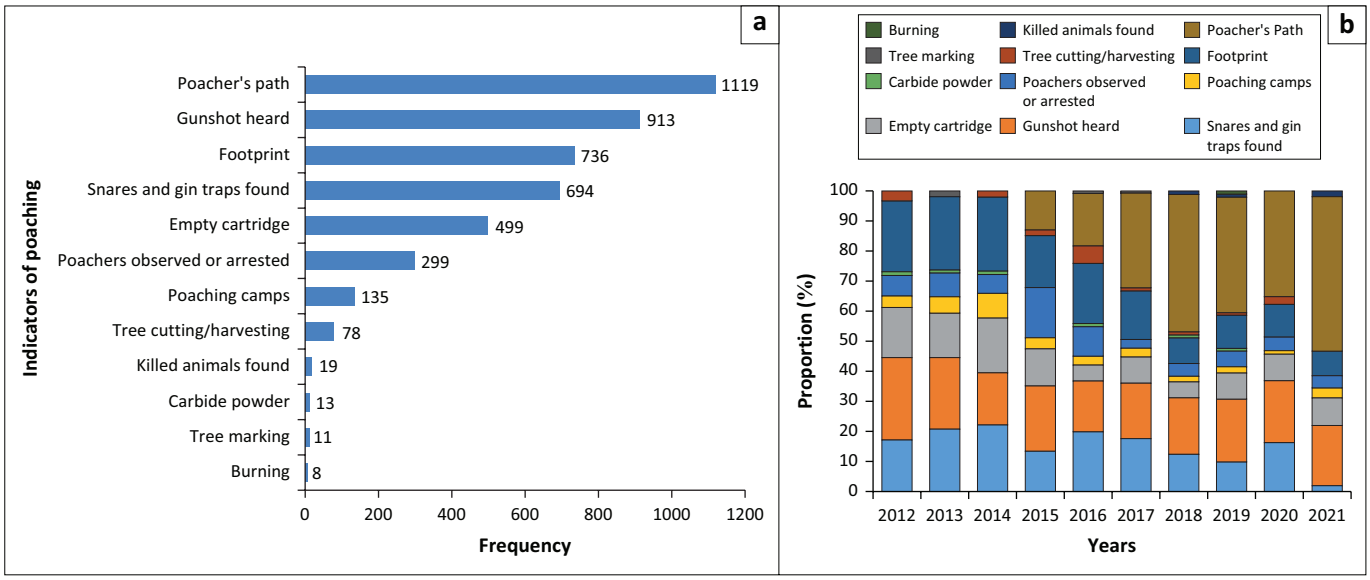


FIGURE 2: Indicators of poaching at the Kakum Conservation Area (2012–2021): (a) Abundance of indicators of poaching. (b) Yearly proportion of indicators of poaching.

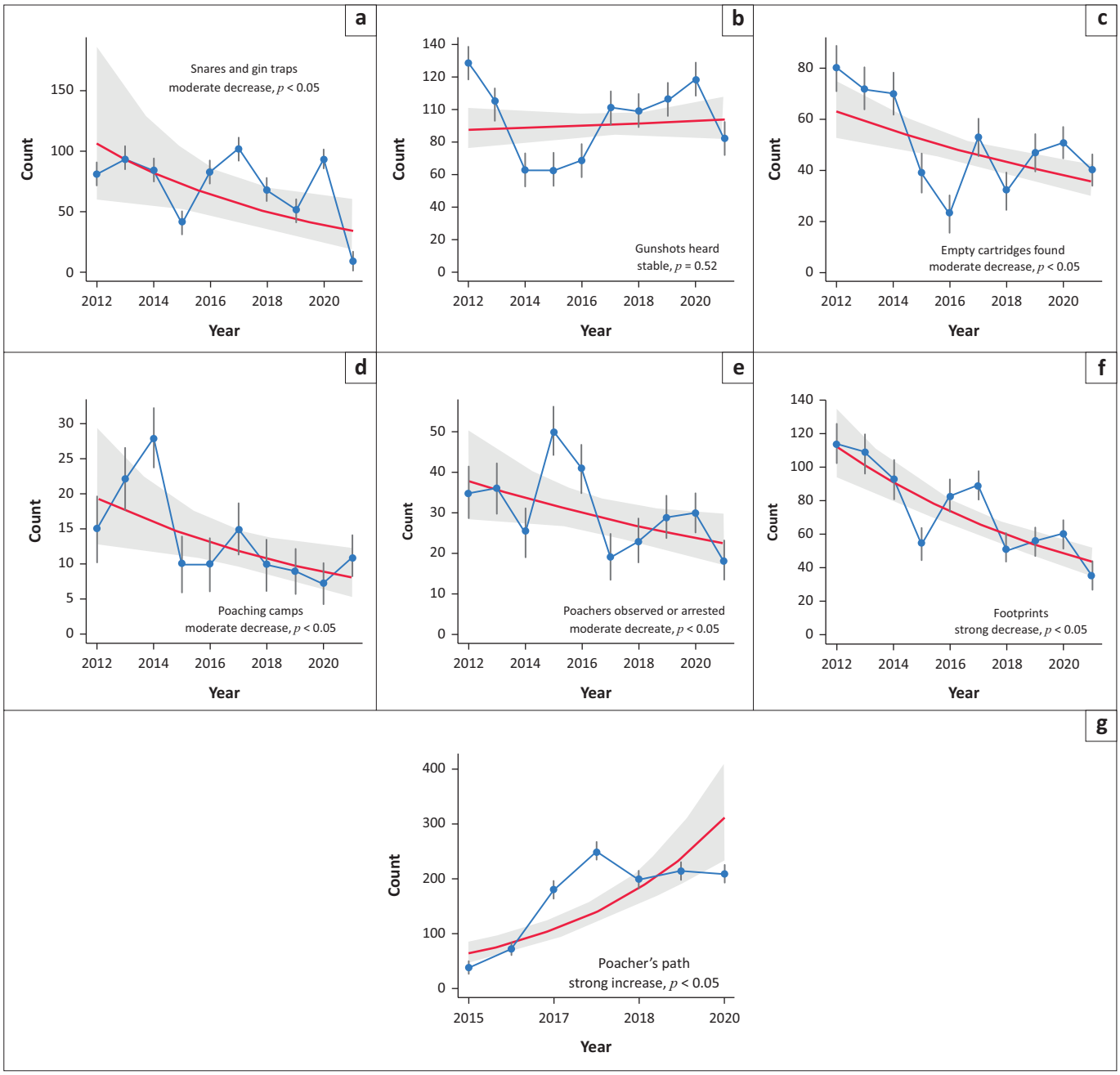


FIGURE 3: Trends in poaching at the Kakum Conservation Area between 2012 and 2021: (a) snares and gin traps found; (b) gunshots heard; (c) presence of empty cartridges; (d) poaching camps; (e) poachers observed or arrested (f) human footprints other than those of patrolling staff and (g) poacher's path.

Effectiveness of law enforcement

The results for the trends in effectiveness of law enforcement at the KCA are shown in Figure 5. Each smaller circle represents 1 year, with months arranged from January to December in a clockwise manner. The height of each bar represents the number of PMD in that month. The scale from 0 to 750 is the same across all years, allowing for direct year-to-year comparisons.

The result in Figure 5 shows temporal variations in the PMD across different months in a single year and across the same months across different years. For example, in 2012, higher patrol efforts were estimated for the following months: January, May, July, September and January. July and September repeatedly showed elevated PMD over several years. This suggests seasonal fluctuations in patrol activities.

The variation in PMD across the surveyed years showed a pattern of generally high and evenly spread patrol efforts, with some months showing very strong coverage between 2012 and 2016. Between 2017 and 2019, patrol efforts appeared more balanced but with lower peaks. There is a noticeable decline in the PMD overall (bars are much shorter) between 2020 and 2021.

The results of this study also show an initial, fairly stable and high annual mean PMD between 2012 and 2016, reaching record values such as 711 PMD. However, from 2017 onward, there is a clear downward trend, with

the lowest annual mean PMD observed between 2019 and 2021 (Figure 6). The difference in this temporal variation of mean PMD at the KCA between 2012 and 2021 is statistically significant (Kruskal-Wallis test: $\chi^2 = 22.96$, $df = 9$, $p = 0.006$). Further test (Dunn's *post hoc* test) showed that the annual mean PMD recorded in 2021 (521.11 PMD) was significantly lower than the annual mean PMD recorded in 2015 (711.01 PMD; $Z = 3.57$, $p = 0.02$), 2016 (695.50 PMD, $Z = 3.14$, $p = 0.04$) and 2017 (685.21 PMD, $Z = 2.93$, $p = 0.04$). Similarly, the annual mean PMD recorded in 2015 was significantly higher ($Z = 3.06$, $p = 0.03$) than that recorded in 2019 (554.79 PMD).

The mean PMD ± SE estimated for the open season of game hunting per the Wildlife laws of Ghana is 650.44 ± 12.68 PMD, whereas that estimated for the closed season is 632.74 ± 20.64. The results also showed no significant difference in the mean PMD between the open and closed seasons at the KCA ($W = 1278$, $p = 0.5$).

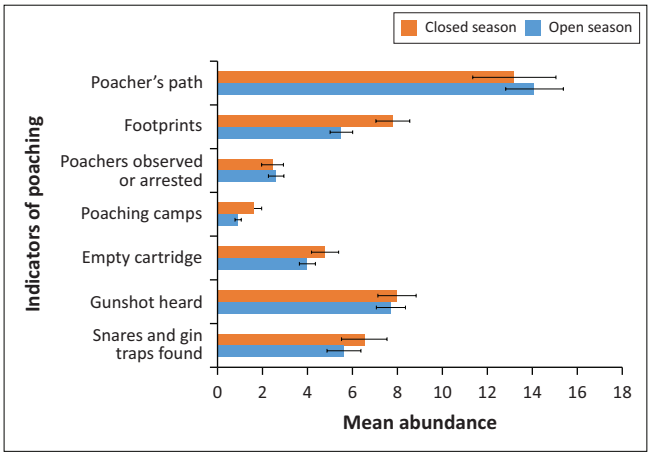


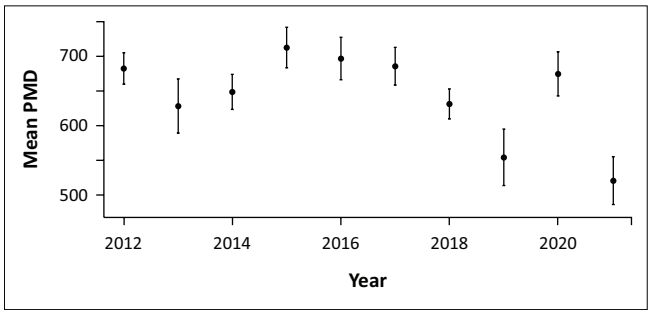
FIGURE 4: Seasonal variation in the mean abundance of footprints of poachers in the Kakum Conservation Area between 2012 and 2021.

Relationship between the effectiveness of law enforcement and indicators of poaching

The relationship between PMD and indicators of poaching showed positive correlations between all but one of the indicators of poaching. In other words, increased patrols ensured better detection rates. Poachers' paths were the only indicator of poaching, which correlated negatively with PMD, meaning more poachers' paths were recorded even when patrolling effort declined. All estimated Pearson's correlation (r) between PMD and indicators of poaching depicted weak correlations. Although weak, the r between PMD and the following indicators of poaching was statistically significant ($p < 0.05$): number of snares and gin traps found and number of empty cartridges (Table 1).

Discussion

This study assessed the trends and levels of poaching in the KCA over a 10-year period (2012–2021), using patrol-monitoring data from the quarterly and annual reports of the law enforcement unit of the park. The findings revealed that the most common poaching indicators in the KCA include



PMD, Patrol Man-Days.

FIGURE 6: Annual mean Patrol Man-Days (PMD) at the Kakum Conservation Area (KCA) between 2012 and 2021.

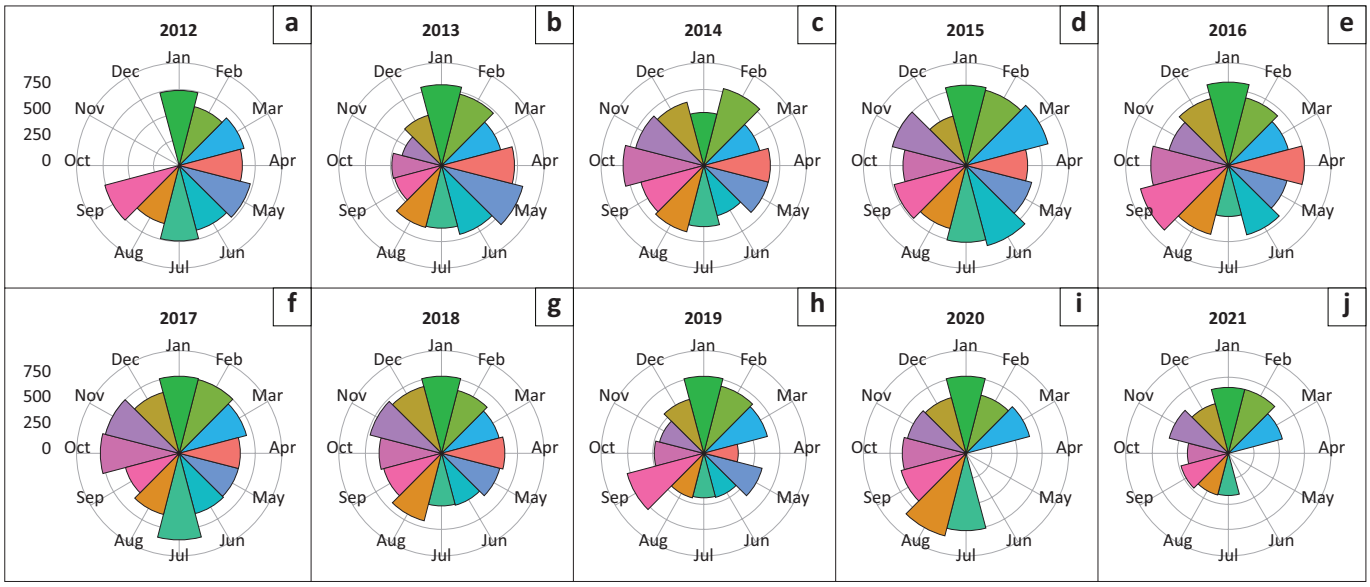


FIGURE 5: Trends in the Patrol Man-Days (PMD) at the Kakum Conservation Area in (a) 2012, (b) 2013, (c) 2014, (d) 2015, (e) 2016, (f) 2017, (g) 2018, (h) 2019, (i) 2020 and (j) 2021.

TABLE 1: Pearson's correlation coefficient between the Patrol Man-Days and indicators of poaching at the Kakum Conservation Area between 2012 and 2021.

Poaching indicator	PMD	
	r	*p*-value
Number of snares and gin traps found	0.23	0.02
Number of gunshots heard	0.05	0.60
Number of empty cartridges	0.21	0.03
Number of poaching camps	0.18	0.05
Number of poachers observed or arrested	0.09	0.37
Number of footprints other than those of the patrol team	0.17	0.07
Number of poachers' paths	-0.19	0.09

PMD, Patrol Man-Days; *r*, Pearson's correlation coefficient.

poachers' paths, gunshots heard, footprints other than those of the patrol team, snares and gin traps and empty cartridges. The long-term trend analysis of poaching indicators showed a decline in most of the poaching indicators. This observation suggests that law enforcement and regular patrolling have contributed to reducing certain forms of poaching activities. This is similar to studies from other Ghanaian PAs, such as the Mole National Park, which also reported declining trends in some poaching indicators, largely attributed to consistent and intensified ranger patrols and increased conservation awareness (Obour et al. 2016; Wiafe 2016). Lindsey et al. (2020) also reported global declines in certain poaching indicators for which enforcement efforts have been sustained. In some national parks in Eastern Africa, for example, intensified patrolling has resulted in a reduction in the encounter rates of snares and gin traps (Musyoki et al. 2012). However, the increase in poachers' paths observed in the KCA according to this study could imply an adaptive strategy employed by hunters to avoid detection. Such an observation could also be a result of poachers changing to using different methods or using different areas, thereby increasing the encounter rates of poachers' paths. Instead of establishing visible camps, setting numerous snares or discharging firearms – activities that are easier for patrol teams to detect – poachers may increasingly rely on discreet movement to access hunting grounds and exit quickly with minimal evidence, thereby increasing the extent and coverage of their path. This finding confirms some of the strategies employed by poachers to outwit patrol staff, as reported by Forsyth and Marckese (1993).

Firstly, the hypothesis that poaching would be lower in the closed season was not supported. Apart from footprints, which were more common in the closed season, there were no significant seasonal differences in other indicators. This observation suggests that Ghana's closed-season regulations are not being fully respected or enforced. Similar observations have been made within the Atewa Range Forest Reserve, where bushmeat continued to be sold during closed periods (McCullough et al. 2007). Although the closed season legally prohibits hunting (except for greater cane rats), increased demand for bushmeat during certain periods, coupled with weak compliance and enforcement, may incentivise covert poaching activities. This demand probably explains the slight increases in activities during the closed season (Figure 4). Across the sub-region, seasonal variations in poaching often follow household economic cycles rather than legal hunting seasons, with poaching peaking during periods when farming activities and food supplies are low (Duffy & St John 2013; Kühl et al. 2009).

Seasonality in patrol effort is often associated with predictable environmental and regulatory factors, which influence both ranger operations and poaching risk. The high PMD observed in January, July and September may be related to various reasons. January often coincides with the dry season in southern Ghana, when vegetation dries out and bushfires (both wild and controlled) become more frequent. Dry conditions can increase accessibility into previously dense forest areas, prompting management to intensify patrols to reduce fire risks and monitor illegal entry. For example, in Mole National Park and Ankasa Conservation Area, dry season patrols are often prioritised because of easier ground accessibility and less dense foliage, improving visibility of snares and camps (Burton 2010). September marks the early period of the closed season. Patrols may be intensified during this transition to enforce compliance and deter illegal hunting that may arise as hunters test the boundaries before or after restrictions formally come into effect.

Secondly, the hypothesis that increased patrol effort reduces poaching was also not confirmed. Patrol efforts were relatively strong from 2012 to 2016 but declined sharply from 2017 onwards, reaching their lowest point between 2019 and 2021. This decline coincided with greater inconsistency in patrol deployment. Weak yet positive correlations between PMD and poaching indicators suggest that more patrols led to more detections, rather than fewer incidents, at least in the short term. This relationship does not necessarily indicate that poaching itself increased; rather, it suggests that more patrols led to more opportunities to detect poaching, especially in areas where illegal activities were previously under-reported. In other words, detection improved, but the underlying incidence of poaching may not have declined immediately. Similar patterns have been noted in the KNP by Wiafe and Amoah (2012). Also, in the Serengeti National Park, increased patrols initially revealed more poaching activities before longer-term reductions were achieved (Hilborn et al. 2006). Patrols detect poaching activities rather than immediately deter. That is to say, rangers can respond only to incidents they find. Detection does not instantly stop all poaching. Sustained and optimised patrols, with consistent coverage, timing and intensity, could yield long-term positive impacts on reducing poaching. The sharp decline in PMD in recent years likely reflects both limited resources and the disruption caused by the COVID-19 pandemic, which undermined conservation financing and patrol capacity across Africa (Lindsey et al. 2020). The COVID-19 pandemic affected patrols by restricting ranger movements as a result of lockdowns, limiting staff availability, reducing funding and logistical support and disrupting routine patrol schedules. These constraints led to fewer patrols and

reduced enforcement coverage, making it more difficult to detect and deter illegal hunting activities. These findings highlight the fragility of enforcement systems when exposed to wider socio-economic shocks.

To improve the effectiveness of law enforcement, patrol strategies must move beyond sheer effort and adopt more targeted, data-led and adaptive approaches. This activity includes prioritising patrols in high-risk zones, such as along frequently used access routes and boundary areas. Patrol timing should be aligned with periods of heightened poaching risk, such as the dry season and peaks in bushmeat demand. Sustained investment in ranger recruitment, training, motivation and welfare is critical to maintaining consistent patrol coverage and morale. In addition, strengthening logistical support through improved transport, communication systems and data-driven patrol planning tools would enhance patrol efficiency, detection capacity and rapid response to illegal activities.

While the overall decline in many poaching indicators is encouraging, the persistence and, in some cases, the increase of activities like poachers' paths highlight the limitations of relying on enforcement alone. Long-term solutions require approaches that complement patrols with community engagement, alternative livelihoods and strategies to reduce demand for bushmeat. In Ghana, community-based ecotourism, despite its own challenges, has shown potential to reduce reliance on poaching by creating new livelihood opportunities (Mensah 2017). Similarly, in Namibia, sharing benefits from community-based conservation activities has shown that local people can be motivated to protect wildlife (Scanlon & Kull 2009; Störmer et al. 2019). Globally, the most effective anti-poaching strategies are those that combine enforcement with technology and strong community participation (Kamminga et al. 2018; Kashyap et al. 2024; Lynam et al. 2025). These technologies include the Spatial Monitoring and Reporting Tool, which has recently been deployed in some PAs in Ghana, including the KCA. The Spatial Monitoring and Reporting Tool supports systematic patrol planning, spatial recording of patrol effort and the identification of poaching hotspots, thereby enhancing data-driven enforcement. In addition, the capacity of rangers in PAs in Ghana has been strengthened in the use of camera traps, primarily for wildlife population monitoring (Stephenson 2024). This technology can also be used in detecting illegal activities such as poaching and unauthorised access. Other technologies that could further enhance enforcement include GPS tracking and mobile data collection, which allow real-time monitoring of ranger movements and rapid response to poaching incidents, as well as the use of acoustic gunshot detecting systems, which improve detection of illegal hunting in remote or difficult-to-access areas.

Conclusion

This study offers the first long-term assessment of poaching trends and law enforcement in the KCA, drawing on a decade of patrol data. Most direct indicators of poaching, such as snares, cartridges and poachers' camps, declined over time, suggesting that sustained ranger presence reduced detectable hunting pressure. However, the increase in poachers' paths indicates that poachers have not withdrawn from the reserve but have adapted their behaviour by shifting routes and methods to avoid detection. Thus, while patrolling has contributed to suppressing some poaching activities, it has not eliminated illegal access, highlighting the need for more targeted, adaptive and intelligence-led enforcement strategies.

Seasonal hunting laws also had little effect on reducing activity, suggesting gaps in enforcement and compliance. Added to this, the sharp fall in patrol efforts after 2017, exacerbated by the COVID-19 pandemic, highlights how vulnerable conservation is to external shocks and resource constraints.

Protecting KCA in the long term will require more than patrols. Stronger law enforcement must be combined with community engagement, livelihood alternatives and ecotourism opportunities. Only through integrated, people-centred approaches can poaching be reduced, biodiversity be safeguarded and KCA's role as a cornerstone of Ghana's conservation and tourism be secured.

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The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

CRediT authorship contribution

Erasmus H. Owusu: Conceptualisation, Data curation, Formal analysis, Methodology, Supervision, Visualisation, Writing – original draft, Writing – review & editing. Jones K. Quartey: Data curation, Formal analysis, Investigation, Methodology, Supervision, Visualisation, Writing – original draft, Writing – review & editing. Abigail Frimpong: Data curation, Formal analysis, Investigation, Methodology, Visualisation, Writing – original draft, Writing – review &

editing. All authors reviewed the article, contributed to the discussion of results, approved the final version for submission and publication and take responsibility for the integrity of its findings.

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Data availability

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Disclaimer

The views and opinions expressed in this article are those of the authors and are the product of professional research. They do not necessarily reflect the official policy or position of any affiliated institution, funder, agency or that of the publisher. The authors are responsible for this article's results, findings and content.

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