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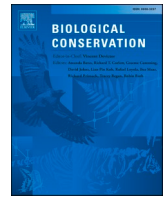
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Orangutan killing and trade in Indonesia: Wildlife crime, enforcement, and deterrence patterns

Julie Sherman^{a,*}, Maria Voigt^a, Marc Ancrenaz^{b,c,d}, Serge A. Wich^e, Indira N. Qomariah^f, Erica Lyman^g, Emily Massingham^h, Erik Meijaard^{c,h}

^a Wildlife Impact, Portland, OR, United States of America

^b Pongo Alliance - Kinabatangan, Kota Kinabalu, Malaysia

^c Borneo Futures, Bandar Seri Begawan, Darussalam, Brunei

^d HUTAN, Sandakan, Malaysia

^e School of Biological and Environmental Sciences, Liverpool John Moores University, Liverpool, United Kingdom

^f Centre for Orangutan Protection (COP), Jakarta, Indonesia

^g Lewis & Clark Law School, Lewis & Clark College, Portland, OR, United States of America

^h School of Biological Sciences, University of Queensland, St Lucia, Australia

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ABSTRACT

Wildlife poaching and illegal trade threaten the survival of many rare species. We assessed spatiotemporal patterns in illegal killing, injury, capture, possession, and sale of orangutans, as well as law enforcement efforts, and conservation interventions affecting Critically Endangered orangutans in Indonesia from 2007 to 2019 using data collected from published and unpublished sources. We found 2229 reported crimes during the study period, including killing and non-lethal crimes. Annual crime rates did not show a declining trend overall during the study period. Most crimes, 99.6 % for Bornean orangutans (*Pongo pygmaeus*), and 95.7 % for Sumatran (*P. abelii*) and Tapanuli (*P. tapanuliensis*) orangutans combined, involved local not international trade. A total of 22 court cases (0.9 %) related to 2229 reported crimes; 20 of these cases led to convictions. At expected detection rates of less than 10 %, average estimated species mortality from killing was 14.3 % for Tapanuli and Sumatran orangutans combined, and 5.1 % for Bornean orangutans. This exceeds the 1–2 % orangutan hunting mortality threshold expected to drive populations to extinction. National parks with orangutans had 0.28–2.11 enforcement officers per 100 km², below the 3–11 officers per 100 km² considered global best practice to deter poaching. The most prevalent interventions to address orangutan crime—education and handovers of illegally held animals—have been conducted without an associated decline in crimes. These tactics alone are insufficient to address orangutan-related crimes. Substantial increases in patrols, investigations, arrests, and convictions, as well as community-focused solutions are urgently needed to halt orangutan killing and trade.

1. Introduction

Wildlife harvest for food and trade is a global threat to biodiversity (IPBES, 2019). The illegal wildlife trade in particular threatens numerous species and disrupts crucial ecosystem services (UNEP, 2016). Addressing this illegal trade is a component of the United Nations Sustainable Development Goals, which call for countries to urgently address both poaching and trafficking (United Nations, 2020). This is especially a concern for the southeast Asia region, which has emerged as a global hotspot of illegal wildlife trade (Felbab-Brown, 2011). Numerous species endemic to this region, including rhinoceroses, tigers, pangolins,

gibbons, and orangutans, are protected by law but nonetheless illegally traded (Felbab-Brown, 2011; Krishnasamy and Zavagli, 2020). A key challenge is that illegal hunting and possession of protected wildlife are commonplace and conducted with impunity in several Southeast Asian countries (Krishnasamy and Zavagli, 2020). Further, in some parts of the region, possessing wild animals as pets is a cultural symbol of wealth and importance (Krishnasamy and Zavagli, 2020). Improved knowledge of wildlife crime patterns and outcomes of interventions to reduce demand and prevent poaching are important to develop effective deterrence for these imperiled species (Kurland et al., 2017).

Strategies to prevent wildlife crime aim to deter criminal acts and to

* Corresponding author.

E-mail address: julie@wildlifeimpact.org (J. Sherman).

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reduce opportunities for these acts to occur (Kurland et al., 2017). There are numerous approaches to deterrence, which can be grouped as either (1) regulatory or law enforcement, an approach relying on monitoring, investigation of compliance, and punishment of law breaking; or (2) non-regulatory approaches which focus on economic, moral, social or other benefits or disincentives to encourage compliance (Kahler and Gore, 2012; Kurland et al., 2017). Diverse interventions to address wildlife crime have been implemented across the world (Kurland et al., 2017). Studies of anti-poaching patrols, such as those using SMART software, show patrolling is effective in reducing poaching crimes when strategically targeted and sufficiently frequent (Critchlow et al., 2017; Linkie et al., 2015). Studies on the effect of non-regulatory approaches suggest these strategies can also be important elements of a comprehensive and locally relevant deterrence program, particularly as they relate to wildlife crimes committed by subsistence hunters or in response to human wildlife interactions (Kurland et al., 2017; Moreto, 2019). However, without any law enforcement, non-regulatory approaches have not been sufficient to deter crime at broad scales (Fairbrass et al., 2016; Keane et al., 2008). The value of strengthening enforcement solely through increased severity of punishments is much debated, with both general criminological and wildlife crime-specific literature suggesting that the likelihood of apprehension, rather than severity of punishment, is crucial to successfully deterring crime (Nagin, 2013; Wellsmith, 2011). This study aims to contribute to understanding of crime trends and the effects of regulatory and non-regulatory approaches applied to address crimes affecting the three species of orangutans (*Pongo* spp.) in Indonesia.

This study analyzed trends in orangutan-related crime in Indonesia, the only country where Critically Endangered Tapanuli (*Pongo tapanuliensis*) and Sumatran orangutans (*P. abelii*) occur (Nowak et al., 2017; Singleton et al., 2017), and also home to approximately two-thirds of the Critically Endangered Bornean orangutans (*P. pygmaeus*) (Ancrenaz et al., 2016). Orangutan capture, killing, harm (injury or harassment) and trade (possession, sale, purchase, exchange or barter) have been banned in Indonesia since 1932 (Ministry of Forestry, 1990). These crimes are subject to maximum penalties of five years imprisonment and fines of IDR 100 million (the equivalent of approximately \$7000 USD as of September 2021), but sentencing is generally lenient (Nijman, 2017). Illegal killing and trade have been consistently identified as significant threats to orangutans for more than 50 years (Harrisson, 1961; Nijman, 2017; Rijksen and Meijaard, 1999). In Indonesia, orangutans are killed opportunistically for bushmeat, as a pre-emptive step to prevent crop foraging or interaction with humans, in retaliation for crop foraging or human interactions, and to obtain infants as pets (Meijaard et al., 2011; Singleton et al., 2017). Obtaining dependent infant orangutans nearly always necessitates killing of the mother (Russon, 2009). Orangutans have been popular as pets in Indonesia for several decades (Nijman, 2017; Rijksen and Meijaard, 1999), a situation that persists today (Sherman et al., 2020). Orangutan distribution in Indonesia encompasses many cultures and religions, and significant income and well-being disparities, all of which play a role in differing perceptions of and behavior towards orangutans at the local level (Chua et al., 2020; Meijaard et al., 2011; Santika et al., 2019). Orangutan killing and local pet trade are also linked with forest clearing and other anthropogenic habitat impacts, and all are primary concerns for the survival of the species (Meijaard et al., 2020; Santika et al., 2017; Voigt et al., 2018).

The law enforcement approach to orangutan-related crime in Indonesia has long been criticized as wholly inadequate because of its near exclusive focus on seizure or surrender of illegally held orangutans, (CITES/GRASP, 2006; Nijman, 2017; Sugardjito and van Schaik, 1992), and capturing and moving injured or at risk wild orangutans away from humans or out of fragmented forest patches (Sherman et al., 2020). Few of these crimes have been investigated, and arrests, trials, prosecution, and convictions are extremely rare (Nijman, 2017; Sherman et al., 2020). Authority for enforcement of wildlife laws, including patrolling and decisions on whether to investigate, confiscate, or to pursue arrests

and prosecutions, rests with provincial government departments of the *Balai Konservasi Sumber Daya Alam* (BKSDA), Indonesia's Natural Resources Conservation Agency, which is a division of the Natural Resources and Ecosystem Conservation Directorate (*Konservasi Sumber Daya Alam Ekosistem* (KSDAE)) of the Indonesia Ministry of Environment and Forestry (Nijman, 2005). BKSDA also is responsible for management of protected areas outside national parks and patrols within these areas, while the Directorate General of KSDAE manages national parks and patrols therein (KSDAE, 2020). Non-governmental organizations (NGOs) supplement or support government efforts on wildlife crime through care of illegally held orangutans, funding rangers and wardens, monitoring of selected habitats, public education on orangutan conservation and the laws protecting orangutans, capacity building for alternative livelihoods and mitigation of negative human-orangutan interactions, and detection and support for investigation and prosecution of orangutan crime cases.

Patrols, equipping and training rangers, and removing hunting snares have been found to be effective in reducing opportunities for poaching and decreasing killing of great apes, including orangutans (Junker et al., 2019; Sugardjito and Adhikerana, 2010). Monitoring and regular researcher presence has likewise been shown to deter great ape killing (Campbell et al., 2011; Junker et al., 2019; Sugardjito and Adhikerana, 2010).

Since the 1970s, both NGOs and government agencies in Indonesia have established rescue centers to facilitate law enforcement through care of confiscated or surrendered animals (Russon, 2009). Demand reduction and awareness raising efforts, typically via rescue centers conducting community education on orangutan protection laws in local communities and in national and local media, have likewise been conducted in Indonesia since the 1970s (Aveling and Mitchell, 1982). Surveys carried out in the past two decades show between 73 and 100 % of respondents in Kalimantan and Sumatra are aware of the laws protecting orangutans and the illegality of owning, selling, or killing them (Meijaard et al., 2011, Anon. pers. comm.; Rainer et al., 2020). While education can support active regulatory efforts (Salazar et al., 2019), evidence suggests education alone is not effective in halting wildlife crime (Baruch-Mordo et al., 2011; St. John et al., 2018; Travers et al., 2019), and its effects are rarely well monitored (Cox et al., 2020; Veríssimo and Wan, 2019). NGOs also use human-orangutan interaction mitigation techniques in some areas (vide: IAR, 2018; OIC, 2019). However, the continued intake of illegal pet orangutans into rescue centers and recent high profile cases of orangutans severely injured or killed in interactions with humans in Sumatra (e.g. Stack, 2019) and Kalimantan (e.g. Galdikas, 2018) suggest that other interventions, including stronger enforcement of existing wildlife laws, are needed to prevent orangutan crimes and protect wild populations.

Orangutan-related crime in Indonesia offers a valuable case study on the effects of addressing poaching and illegal trade of a threatened species primarily through seizures or surrenders and non-regulatory interventions centered on rescue and education. Our study builds on previous analyses of orangutan trade in Indonesia by Nijman (2005, 2009, 2017) and Freund et al. (2017) by assessing trends in orangutan-related crime and, where spatial data were available, comparing those with associated interventions across Indonesia from 2007 to 2019. We developed a unique dataset including orangutan-related crime data from local, national, and international news media; published literature; on-line wildlife crime datasets; publicly reported and unpublished orangutan rescue data; and orangutan conservation intervention data from practitioner-published materials.

This study addresses the following questions: 1) What are the spatial and temporal patterns in orangutan-related crimes and convictions in Indonesia?; 2) How has law enforcement presence been distributed spatially in provinces with orangutan populations?; 3) What are the likely impacts of crimes on orangutan species?; 4) What crime deterrence interventions are conducted across orangutan species distribution, and which of these interventions are spatially associated with changes in

crime rates? We discuss recommendations for policy makers, conservation practitioners, and researchers to improve deterrence of orangutan-related crimes. These considerations are relevant to other heavily poached and traded species.

2. Methods

2.1. Crimes and convictions

We compiled data on reported orangutan killing and non-lethal crimes (injury and trade crimes, i.e. capture, possession, sale, or barter) in Indonesia, and any related law enforcement actions. Our dataset includes available records of both apprehended crimes and crimes that were detected and reported but not acted on. Internationally traded orangutans were included if the animals reportedly originated from and were repatriated to Indonesia. We reviewed studies on orangutan related crime, government annual statistic reports, CITES illegal trade reports, CITES mission reports, newspaper articles, the TRAFFIC Wildlife Trade Portal, and NGO sources (Table A1). We searched Indonesian newspaper websites using the search term “orangutan” to capture relevant news on crimes that occurred in Indonesia between 2007 and 2019 (Table A1). We performed a Google Advanced Search in English and Indonesian to capture search terms “orangutan” and “orang-utan” in news publications from 2007 to 2019. Searches for local orangutan names (*mawas*, *mias*, and *maias*) did not yield relevant results. We compiled publicly reported information from all Indonesian rescue centers that held orangutans, NGOs involved in supporting or monitoring Indonesian wildlife law enforcement, and unpublished information from direct communication with practitioners (Table A1). Articles in Indonesian were translated using Google Translate with help from our Indonesian-speaking authors where necessary.

News articles and reports from rescue centers and government do not cover every detected crime. While we are confident our dataset provides a comprehensive overview of trends in criminal activity affecting wild orangutans in Indonesia, it does not capture undetected crimes and likely underestimates the total number of detected crimes and potentially their spatial extent due to the clandestine nature of wildlife crime and expected underreporting of detected crimes.

For each incident, meaning any situation of killing or non-lethal crime involving orangutans, we captured any available data on crimes, location, and law enforcement variables (Table A2). Many situations involve more than one animal and encompass both types of crime; for example, those involving infants were quantified as one killing crime (the mother) and one non-lethal crime (the illegally held infant). We checked animal name, sex, age, description, number of orangutans affected, incident details, arrest dates, names of persons involved, conviction date, and sentencing outcome for every crime and deleted any duplicates to ensure that each orangutan, crime, and conviction or other law enforcement outcome was represented only once in the dataset. Wherever possible we analyzed multiple sources to confirm information and address data gaps within individual records.

We quantified killing and non-lethal crimes in Indonesia from January 1, 2007 (the initiation of a 10-year Indonesian Orangutan Strategy and Action Plan) to December 31, 2019. Some deaths related to initially non-lethal human actions may have occurred subsequent to what our records suggest.

We quantified convictions by court case across Indonesia, and for Kalimantan and Sumatra to compare regional differences. Conviction and crime numbers were not directly comparable, as many cases resulted in convictions of multiple persons for crime affecting a single orangutan, and vice versa. Only 22 cases went to trial, hence data on specific criminal charges were not available for most incidents.

Reported apprehension locations reflect where the animals were discovered in captivity or reported killed. Particularly in the case of illegal pets, these orangutans are likely to have been captured elsewhere and then transported to human residences. This may introduce a bias

towards crimes being reported in urban and suburban areas where animals can be sold or kept. Animals' origin location is typically recorded and reported if known, and thus we captured these data whenever possible. Where data were available, we recorded both origin and apprehension location. Where an instance represented both a killing crime (killing of adult female, generally) and illegal capture and trade or possession of an infant, we used the origin location for the killing crime and the apprehension location for the possession crime. We summed the annual number of killing and non-lethal crimes by administrative province, district (*kabupaten*), subdistrict (*kecamatan*), village (*desa*), and site name. We analyzed annual spatiotemporal changes in crimes using province and available combinations of district, subdistrict, and village location data using the 2014 administrative district boundary layers. All spatial manipulations were performed in Python (Python Software Foundation, 2019) ArcGIS Pro (Esri, 2020) and QGIS 3.14.0-Pi (QGIS, 2020) and data aggregated, analyzed and visualized in Python, R (R Core Team, 2020) and ArcGIS Pro.

Provincial orangutan population estimates in Kalimantan for 2017 were derived from Voigt et al. (2018) by determining the slope of the line between the provincial population estimates for 2008 and 2014, and using this rate to extrapolate the provincial populations for 2017.

We used the Mann-Kendall trend test (McLeod, 2022) to assess trends in annual crime numbers over the study period and the Ljung box test (Lemon, 2006) to assess serial autocorrelation in annual crime numbers. Both tests were run in RStudio 1.3.959 (R Core Team, 2020).

2.2. Detection rates and enforcement effort

This study captures what is likely a small portion of actual orangutan crimes since our dataset includes only illegal incidents reported in the sources we reviewed. These reports encompass detected crimes including those apprehended and those not acted on. Orangutan crime detection rates in Indonesia are presumed to be low owing to the species' remote habitats; limited anti-poaching, investigation and prosecution efforts; corruption; and reluctance to punish local citizens (CITES/GRASP, 2006; Nijman, 2017; Sherman et al., 2020).

We estimated enforcement effort in the national forest estate and in national parks based on the number of wildlife enforcement personnel per 100 km² of forest estate per province, and in all national parks within orangutan distribution. Data were not available on the number of enforcement staff assigned to specific protected areas outside national parks. Enforcement staff numbers were collected from annual government statistics reports. Although many projects conduct SMART patrols in orangutan habitats, we did not have access to these patrol coverage and effort data.

To assess the potential scope of actual orangutan-related crime, we considered how imperfect detection and errors in reporting might underestimate actual crimes. We looked at published detection rates for wildlife poaching and environmental crime—the percentage of actual or estimated total crimes that were detected by enforcement authorities—to determine what likely detection scenarios implied for orangutan killings reported during the study period. We found published rates for the percentage of actual poaching crimes detected in the United States (1.2 %) (Beattie et al., 1977; Kaminsky, 1974); the percentage of illegal logging crimes detected in Indonesia (3.2 %) (Akella and Cannon, 2004), and the percentage of wildlife crimes detected in the Philippines (6.2 %) (Akella and Cannon, 2004), Cambodia and the United Kingdom (10 %) (Claridge et al., 2005). We also tested two aspirational detection rates (24 % and 70 %) for snares found by SMART ranger patrols in Kerinci Seblat National Park in Sumatra (Linkie et al., 2015). Although these higher detection rates focus on snaring, a single type of poaching less common for orangutans (our data show most are killed with guns or machetes), they are nonetheless useful to investigate whether additional deterrence might be achieved with increased and strategically deployed patrol effort. We calculated the total number of killing crimes each of these six detection rates would represent for orangutan populations.

2.3. Interventions to deter crime

We assessed interventions to deter crime by collecting data on activities likely to influence crime deterrence in Kalimantan and Sumatra between 2007 and 2019. We used six activity categories that we deemed likely to affect crime: Research (long-term research projects with regular presence on the ground); Habitat management (habitat purchase, protection and management e.g. fire suppression and hunting controls such as snaring bans or prohibitions on orangutan killing enforced by land owners or managers); Law enforcement (patrols, monitoring, investigation, arrest and other enforcement action); Awareness raising (general public education); Community outreach & capacity building (targeted education and building capacity for alternative livelihoods or other behavior change); Human-wildlife conflict mitigation (deterrence tools, compensation or benefit sharing to address losses) (Table A3).

We identified 161 entities conducting relevant activities in orangutan habitat, 99 based in Kalimantan, 45 based in Sumatra, and 17 based outside orangutan distribution (Table A4), using author knowledge and consultation with local conservation experts. We collected activity data through direct requests to entities and via desktop research and review of publicly available data from grant and project databases, corporate sustainability reports, annual reports, tax filings and charity commission reports, and entity websites (Table A1).

To determine spatial and temporal overlaps in crime and interventions in villages (*desa*), we used the subset of the crime data that included village locations ($n = 1042$ in Kalimantan; $n = 334$ in Sumatra). To test trends in annual crime rates we compared totals of annual reported crimes in four categories of target areas within orangutan distribution provinces: (1) formally protected areas within orangutan distribution including national parks, wildlife reserves, and selected protection forests we identified as having orangutan conservation activities (PA); (2) areas outside formal protected areas but with focused orangutan conservation activities (called “conservation activity areas,” encompassing rescue centers, orangutan reintroduction sites, long-term orangutan research sites, orangutan-related community conservation sites, and essential ecosystem areas (*Kawasan Ekosistem Esensial* (KEE)) (CA); (3) administrative boundaries of major cities and towns; and (4) all unprotected areas (any villages outside PA and CA). Selected target areas are shown in Fig. 1. Activities associated with each target area are detailed in Table A5.

To identify all districts, subdistricts and villages that were contained in or overlapped with target areas, we mapped crime and intervention locations using the 2014 administrative boundary layers; Indonesia protected area boundaries (IUCN and UNEP-WCMC, 2020); and shape files, maps or area descriptions from practitioners. Protected areas included buffer zones delimited by the boundaries of villages that overlap but are not entirely contained within these areas. Any villages not included in target areas were considered unprotected areas. Visualization of crime and intervention locations was done in QGIS.

Most areas had multiple simultaneous interventions, and very few data were available on systematically measured outcomes and impacts, particularly any that accounted for confounding social, political, and ecological factors. We compared available data on intervention types and annual reported crimes by province, target area category, and specific target areas (Tables A5 and A6). We used the Mann-Kendall trend test (McLeod, 2022) to determine positive and negative crime trends.

3. Results

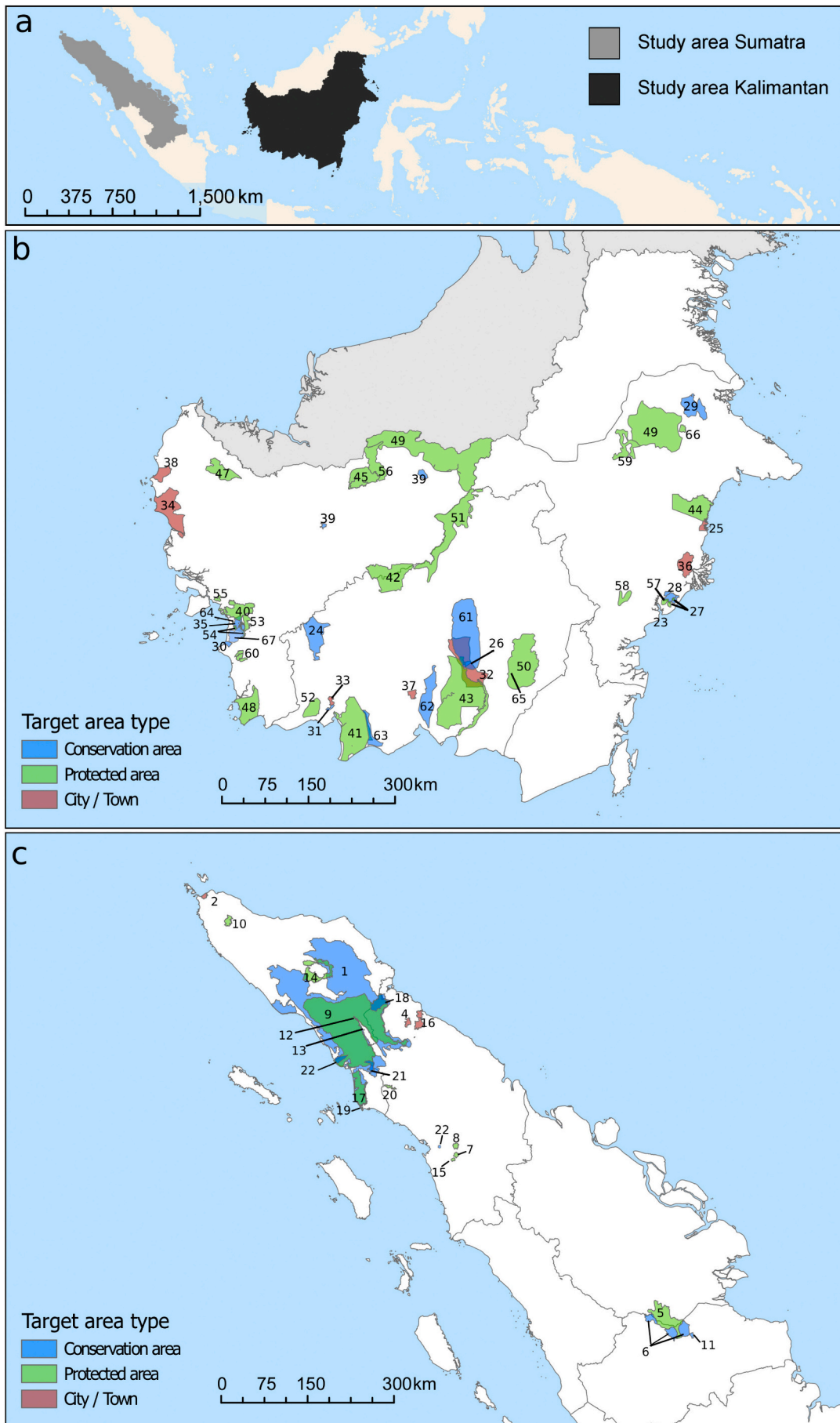
3.1. Spatial and temporal trends in orangutan crime

We found a total of 2229 reported crimes affecting orangutans in Indonesia between 2007 and 2019 (Fig. 2). There were 1712 crimes affecting Bornean orangutans (an average 132 crimes annually), and 517 crimes affecting Sumatran and Tapanuli orangutans combined

(average 40 crimes annually). Tapanuli orangutans were not recognized as a separate species until 2017 (Nowak et al., 2017), and may be underrepresented in crime reports. Annual crime rates did not show a declining trend in either Kalimantan or Sumatra (Table A6). Killing represented about half of the crimes affecting Bornean orangutans in all provinces (52 % in Central and West Kalimantan and 51 % in East Kalimantan), and 43 % of the crimes affecting Tapanuli and Sumatran orangutans combined (Table A7). The remaining non-lethal crimes were capture, possession or sale of infants, harm or capture of wild adult orangutans due to conflicts, and attempted poaching not resulting in death (such as an animal caught in a snare).

A total of 22 court cases related to the 2229 reported crimes. Twenty of these cases led to convictions of 31 people involved in 60 crimes (Fig. 2, Table A8). One additional case led to a customary law warning for five people for an incident involving two Bornean orangutans (Table A8). We found records of two additional cases in 2011 and 2018 that went to trial but did not result in convictions. Many individual crimes related by location or perpetrator, such as those occurring on one plantation or involving a specific trader, were tried together in a single court case, while other cases involved multiple persons convicted for killing a single orangutan. Crimes involving killing or injury of mothers and subsequent capture of infants might be expected to be tried together, but in practice the sources of illegally held infants, including killing of the mothers, were almost never investigated. The crimes in our dataset involving possession of infant orangutans were both temporally and spatially disparate from the killing of the mother in nearly all cases, as the possession crimes were apprehended after the killing when the infant was discovered at the home of its owner or, more rarely, for sale. Ten court cases ending in convictions were related to crimes affecting Sumatran orangutans; nine were related to Bornean orangutans, and one to Tapanuli orangutans. Reported cases leading to conviction have risen since 2013, from two court cases in Kalimantan during 2007–2013 to six during 2014–2019, and in Sumatra from one case during 2007–2013 to seven during 2014–2019 (Table A8). However, prosecutions and convictions remain extremely rare compared to crimes. The highest rate was three cases per year leading to convictions in 2015, 2017, and 2019, as compared to 196, 143, and 136 minimum reported orangutan crimes for those years, respectively (Table A7).

Orangutan-related crime in Central Kalimantan declined notably between 2007 and 2008, following extensive clearing for oil palm and associated human orangutan conflicts prior to 2007 (Santika et al., 2017), but has not shown a declining trend overall ($\tau = -0.333$, $p = 0.127$) (Fig. 3, Table A6). Crimes in East Kalimantan increased since 2015, while in West Kalimantan crimes remained relatively high since 2013. Neither province had a declining trend ($\tau = -0.013$, $p = 1.000$, and $\tau = 0.290$, $p = 0.196$, respectively). Nearly all reported crimes affecting Bornean orangutans in Indonesia (96 %) were in provinces within species distribution. Crimes outside distribution provinces (4 %, $n = 69$) were mainly reported in areas with international shipping ports or airports (Banjarmasin, South Kalimantan; Java), although only 0.5 % ($n = 9$) were definitively connected to international trade (repatriations from Thailand and Kuwait); the rest appeared connected to national trade. Eleven additional Bornean orangutans repatriated from international trade in 2015 were excluded from our dataset because the animals' capture and export from Indonesia likely occurred prior to the study period. The preponderance of crimes affecting Sumatran and Tapanuli orangutans (92 %) occurred in orangutan distribution provinces of North Sumatra and Aceh, and in Riau province (Fig. 4). Riau is outside species distribution but has a reintroduced population of Sumatran orangutans. Aceh has both wild orangutans and a reintroduced population outside species distribution. Crimes reported outside these provinces (8 %, $n = 42$) were primarily from Java, with 4.3 % ($n = 24$) of these connected to international trade (repatriations from Kuwait, Malaysia, and Thailand). Many internationally trafficked orangutans have not been repatriated (Beastall and Bouhuys, 2016) and are excluded from these totals.



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Fig. 1. Study area and target areas in Kalimantan and Sumatra, Indonesia. (a) Overview of study area. Grey areas represent provinces in species distribution per Voigt et al. (2018) and Wich et al. (2016), and provinces with reintroduced orangutan populations. (b) and (c) show target areas by type (protected areas, conservation activity areas, and cities/towns) in Kalimantan and Sumatra, respectively. Target area numbers correspond to Table A5, which includes list of activities undertaken in each. Where shape files for a target area were not available, all village administrative units (*desas*) in the target area are shown. Kalimantan, Indonesia provinces in (b) are white, grey shaded areas are outside Indonesia.

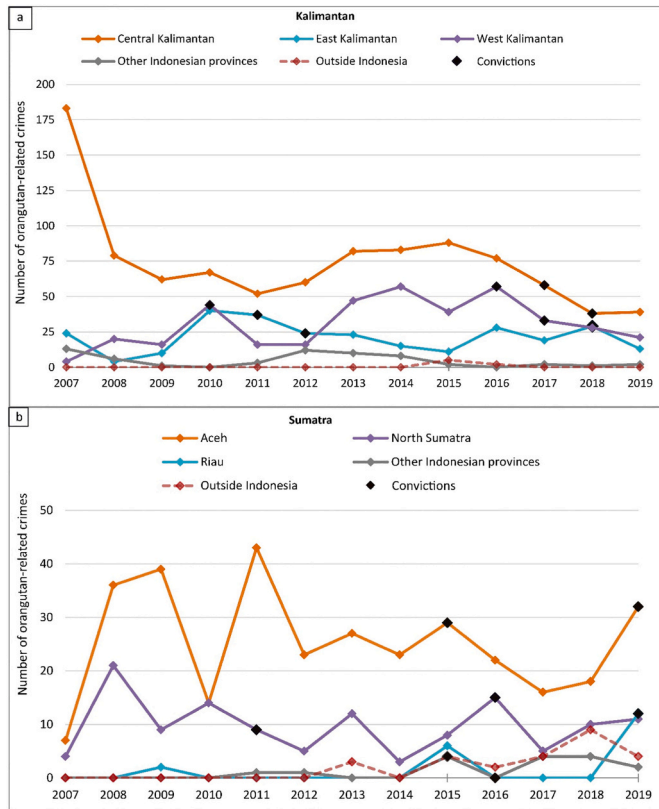


Fig. 2. Annual reported orangutan crimes and convictions in Kalimantan and Sumatra, Indonesia from 2007 to 2019.

a) Summed annual totals of reported crimes affecting Bornean orangutans detected within species distribution in provinces of Central, East, and West Kalimantan; in other Indonesian provinces outside species distribution; and international locations outside Indonesia. Orangutans are present in low numbers in North Kalimantan province but no crimes were reported there during study period. b) Summed annual totals of reported crimes affecting Tapanuli and Sumatran orangutans detected within species distribution in Sumatra provinces of Aceh and North Sumatra, and in Riau where a population has been reintroduced; in other Indonesian provinces outside species distribution; and international locations outside Indonesia. The reintroduced population also extends into Jambi province but no crimes were reported there during study period. Black diamonds indicate years and provinces with court cases ending in convictions.

Reported crimes were higher in and around national parks and protected areas, and areas where rescue and research organizations work (Fig. 1, Table A5). The spatial overlap of orangutan-related crimes in Kalimantan (Fig. 3) and Sumatra (Fig. 4) shows crime was present in all time periods in subdistricts in and around National Parks and other areas where rescue centers and anti-poaching efforts are focused (Fig. 1, Table A4). Most areas of Kalimantan with relatively high numbers of crimes persisted throughout the study period from the earliest time period (2007–2010), as well as spreading further across orangutan distribution in subsequent time periods (Fig. 3).

Crimes in Sumatra were reported in and around protected areas and the city of Medan (Fig. 4), where rescue organizations are headquartered

(Fig. 4). Crimes reported around the city of Banda Aceh decreased over time, and none were reported in the latest time period (Fig. A1). No crimes were reported in or around the reintroduced populations in Aceh (Jantho Nature Reserve), or in Riau and Jambi provinces (Bukit Tigapuluh National Park). Crimes reported within Tapanuli orangutan distribution increased in the latest time period (2017–2019) (Fig. A2). At least 11 reported crimes involved Tapanuli orangutans, including five killings.

3.2. Enforcement effort

Density of enforcement officers—rangers and other government personnel with enforcement authority—is low in both Kalimantan and Sumatra, with 1.9 or fewer provincial officers per 100 km² of forested estate in all provinces in orangutan distribution and where orangutans have been reintroduced, and 2.1 or fewer officers per 100 km² of national park lands (Table 1). The highest enforcement officer density was 2.1 officers per 100 km² in Gunung Palung National Park in Kalimantan. Despite larger orangutan populations and habitat area in Kalimantan, the highest provincial enforcement officer density there (0.7 officers/100km² in East Kalimantan) is equal to the lowest provincial density in Sumatra (0.7 officers/100km² in Riau). Comparison of park size, enforcement officer density, and crimes rate showed that the largest parks have lower enforcement officer densities. The largest park, Gunung Leuser National Park, had 0.44 officers per 100 km² for 10,946 km², while Bukit Tigapuluh National Park had 1.66 officers per 100 km² in a 1442 km² park (Table 1). The highest crime rate (n = 42) was in Tanjung Puting National Park which had 0.51 officers per km², while Betung Kerihun National Park had the lowest officer density at 0.28 officers per 100 km² and no reported crime (Table 1). Practitioners we spoke with and unpublished patrol coverage maps indicated that only small portions of protected areas are covered by patrols, and additional personnel and resources including patrols stations and equipment are necessary to increase coverage (authors' unpublished data). Enforcement efforts are supplemented by NGO and community supported ranger patrols and wildlife crime investigators both inside and outside of federally protected areas, although these additional personnel do not have authority to make arrests or otherwise enforce laws and are not reflected in Table 1.

3.3. Detection rates for orangutan crimes

The actual number of orangutan-related crimes committed but not detected, and those detected but not acted on is unknown. The prevalence of crimes indicated by community survey responses and records of wildlife crime researchers and NGOs suggest that only a small percentage of actual orangutan crimes are detected and apprehended (Freund et al., 2017; Massingham unpublished data; Meijaard et al., 2011). Low detection and apprehension rates are common for wildlife crime (Wellsmith, 2011). We applied six published detection rates to Kalimantan provincial orangutan populations calculated from Voigt et al. (2018) and Sumatra orangutan populations estimated in Wich et al. (2016) (Table 2). Under the most likely scenarios of detection rates below 10 %, the average percent orangutan mortality from illegal killing from 2017 to 2019 was 6.3 % for Bornean orangutans and 14.3 % for Sumatran and Tapanuli orangutans combined. A 10 % detection rate yielded population mortality rates of 1.4 % to 3.3 %.

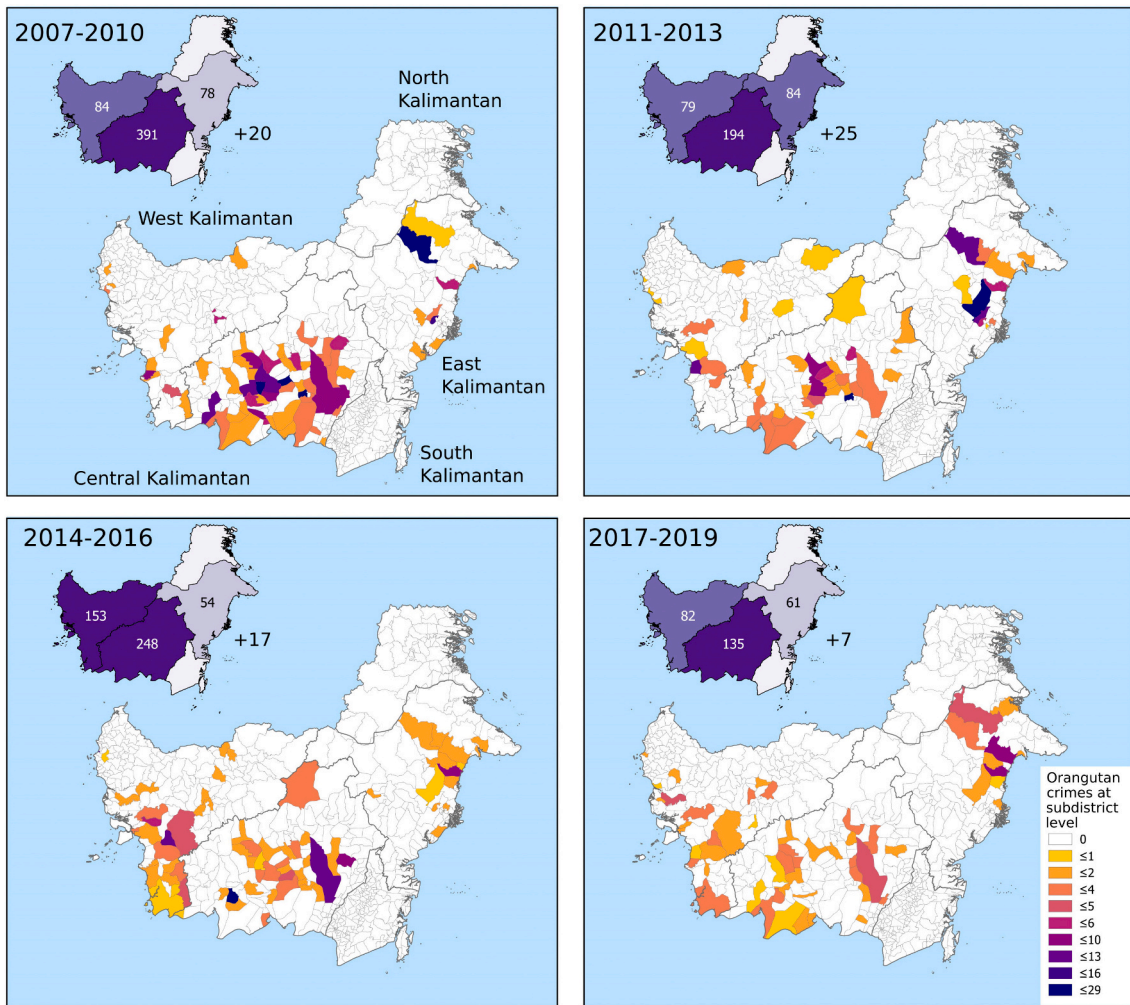


Fig. 3. Spatial distribution of reported crimes affecting *P. pygmaeus* from 2007 to 2019 in Kalimantan, Indonesia. Upper left inset maps show total crimes ($n = 1712$) by time period across West, Central, and East Kalimantan provinces which encompass nearly the entirety of *P. pygmaeus* distribution (Voigt et al., 2018). Numbers in shaded province shapes are the crimes reported within those provinces; the number adjacent to map is the total of crimes reported in provinces outside species distribution within Kalimantan, and elsewhere in Indonesia. Main maps show the subset of crimes within West, Central, and East Kalimantan provinces with sub-district location data ($n = 1131$). Few sub-district location data were available for crimes in West Kalimantan from 2007 to 2010 hence these crimes may be under-represented in the sub-district map for this time period. The 2007–2010 time period is expected to have more crimes overall as it includes an additional year of crime data compared to other periods, and it includes the year with the highest number of total crimes (2007; $n = 224$). Not all subdistricts shown in West, Central, and East Kalimantan have orangutan populations, but crimes were reported in subdistricts both inside and outside orangutan distribution.

3.4. Trends in orangutan-related crime and interventions to deter crime

Using the subset of reported crimes with village locations within orangutan distribution provinces ($n = 1042$ in Kalimantan; $n = 334$ in Sumatra), we compared annual crimes in target areas with orangutan conservation interventions (Table A5). We tested for trends in annual crimes reported in the following areas in Kalimantan and Sumatra orangutan habitat provinces: (1) unprotected lands; (2) formally protected areas; (3) conservation activity areas; and (4) major cities and towns (Table A6). Target areas and cities and towns are listed in Table A5. Although orangutans do not occur within urban areas, we found many crimes involving wild orangutans were reported within the administrative boundaries of cities or towns, often at the edges of urban areas or in new developments in converted forests. Additionally, many pet orangutans were seized from or surrendered by city or town residents.

Mann-Kendall trend tests showed that annual reported crimes increased significantly across all unprotected lands in West Kalimantan ($\tau = 0.484$, $p = 0.027$), and decreased significantly across unprotected and protected lands in Central Kalimantan ($\tau = -0.487$, $p = 0.024$;

$\tau = -0.468$, $p = 0.032$, respectively; Table A6). Reported crimes decreased significantly in major cities and towns across all orangutan distribution provinces in Kalimantan ($\tau = -0.581$, $p = 0.007$) and in Central Kalimantan ($\tau = -0.641$, $p = 0.003$). Reported crimes notably decreased in many areas following implementation of deterrence activities including patrols and community projects during the study period, for example in the Katingan Mentaya protected area ($\tau = -0.634$, $p = 0.006$) and Rungan Landscape conservation activity area (not a statistically significant trend) (Tables A5 and A6, Fig. A3). Some protected areas with patrols, habitat management, and community projects including Lamandau River Wildlife Refuge, Betung Kerihun National Park, and Bukit Baka Bukit Raya National Park had no crimes during the study period, while Gunung Palung National Park had only one. However, crimes were reported in recent years in areas that partially overlap with national parks with key orangutan metapopulations in Tanjung Puting and Kutai National Parks despite ongoing deterrence activities (Fig. A3). No crimes were reported in the Gunung Palung research site in West Kalimantan, but crimes were reported in the villages in Mawas conservation activity area and in Kutai National Park that overlap the Tuanan and Kutai research sites, respectively.

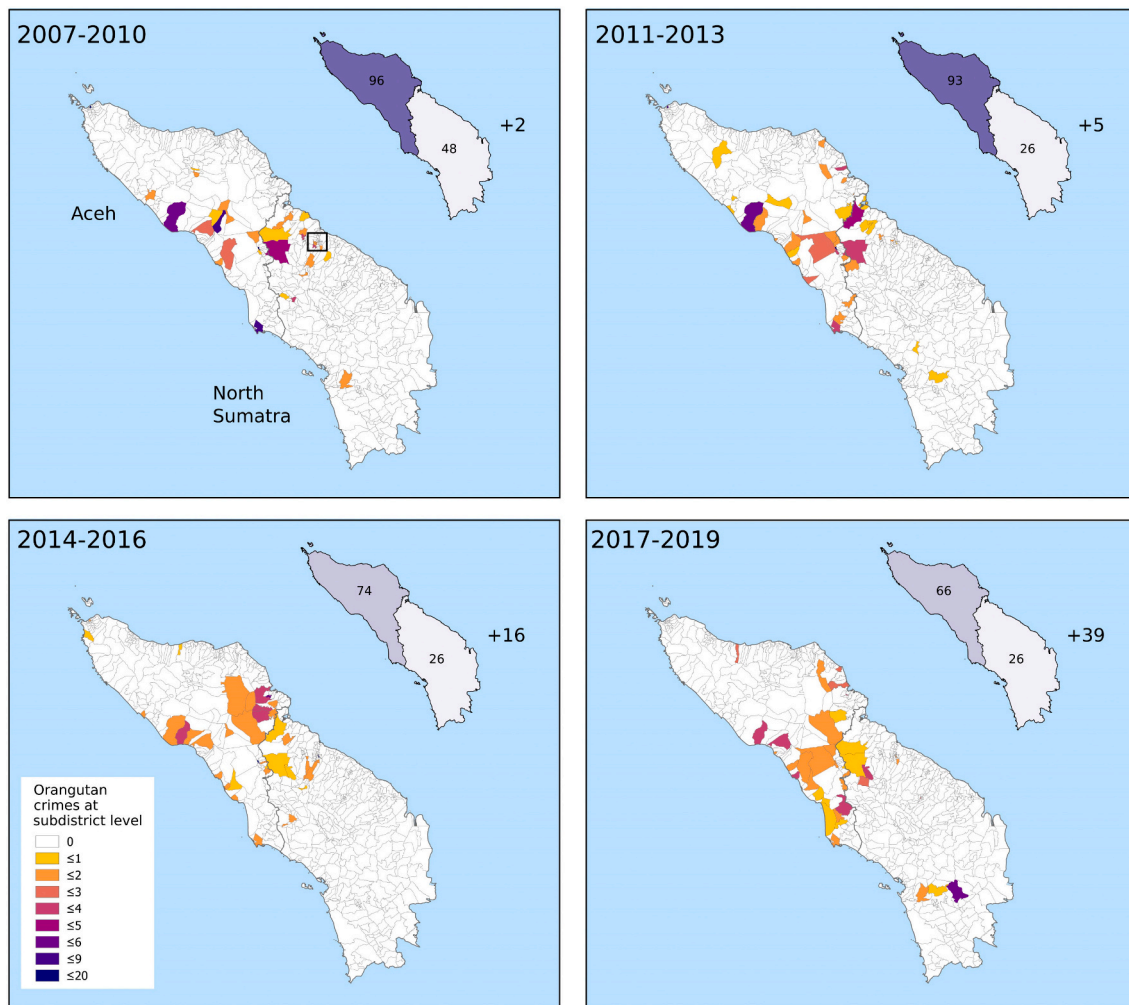


Fig. 4. Spatial distribution of reported crimes affecting *P. abelii* and *P. tapanuliensis* from 2007 to 2019 in Sumatra, Indonesia. Upper left inset maps show total crimes ($n = 517$) by time period across Aceh and North Sumatra provinces which encompass *P. abelii* and *P. tapanuliensis* distribution per Wich et al. (2016). Numbers in shaded province shapes show the crimes reported within those provinces; the number adjacent to map is the crimes reported outside species distribution within Sumatra (including reintroduced populations in Riau and Jambi provinces), and from other areas in Indonesia. Main maps show crimes in Aceh and North Sumatra provinces with subdistrict location data ($n = 409$). The Medan urban area is marked with a rectangle. Detailed maps of Banda Aceh, Gunung Leuser National Park, and Tapanuli habitat area crimes are in Figs. A2 and A3. The 2007–2010 time period is expected to have more crimes overall due to the additional year of data compared to other periods. Not all subdistricts shown in Aceh and North Sumatra have orangutan populations, but crimes were reported in subdistricts both inside and outside orangutan distribution.

In Sumatra, annual reported crimes increased significantly across all protected areas ($\text{tao} = 0.586$, $p = 0.009$) and all conservation activity areas ($\text{tao} = 0.480$, $p = 0.031$), while crimes reported across major cities and towns decreased significantly ($\text{tao} = -0.494$, $p = 0.023$) (Table A6). This decrease in reported crime in urban areas is largely due to the significant decline in Banda Aceh in Aceh province ($\text{tao} = -0.516$, $p = 0.027$). Urban areas Medan and Kutacane had statistically insignificant increases in crimes over the study period and remain areas of concern due to relatively high crimes rates since 2015 (Fig. A4). Reported crimes significantly increased in protected area Gunung Leuser National Park in Aceh province ($\text{tao} = 0.523$, $p = 0.029$), despite all types of interventions occurring throughout the study period. No crimes were reported at long-term research sites in Sumatra (Fig. A4), or in Bukit Tigapuluh National Park, Jantho Nature Reserve, Dolok Sipirok, Dolok Sibual-Buali, and Lubuk Raya protected areas, all of which had patrols or monitors.

Total numbers of reported crimes were highest overall in unprotected areas where in most cases education was the only orangutan conservation intervention conducted (Table A5, A9). Urban areas Bontang in East Kalimantan, Sampit in Central Kalimantan, and Medan in

North Sumatra, have consistently been hotspots for orangutan crimes (Fig. A3).

4. Discussion

4.1. Crime trends

Orangutan-related crimes in Indonesia have not declined overall between 2007 and 2019. Crimes affecting Sumatran and Tapanuli orangutans were approximately two times higher than those affecting Bornean orangutans as a percentage of estimated species population (Table 2). This offtake pressure is a serious concern given the relatively small population and habitat extent of Sumatran orangutans, and the less than 800 remaining Tapanuli orangutans (Wich and Meijaard, 2021).

Changes in reported crimes in Kalimantan may reflect increases in detection and apprehension efforts by rescue centers. Central and East Kalimantan had higher reported crimes in the earliest time period when those areas had the only significant rescue center capacity in Kalimantan. Reported crimes expanded across West Kalimantan following

Table 1
Enforcement effort and reported crime rates in provincial forest estate lands and National Parks.

Provincial enforcement	Forested estate ^a area (km ²)	Enforcement officers ^b per 100 km ²	Total crimes reported, all years ^c
Sumatra			
Aceh	35,638.13	1.0	329
North Sumatra	30,557.95	1.9	128
Jambi	20,985.35	1.6	0
Riau	54,069.92	0.7	20
Kalimantan			
West Kalimantan	81,986.56	0.5	400
Central Kalimantan	126,971.65	0.4	962
East Kalimantan	83,391.51	0.7	277
Protected areas enforcement ^d	Protected land area (km ²)	Enforcement officers per 100 km ²	Total crimes reported, all years ^e
Sumatra			
Gunung Leuser NP	10,946.92	0.4	23
Bukit Tigapuluh NP	1442.23	1.7	0
Kalimantan			
Bukit Baka Bukit Raya NP	1810.9	0.7	0
Sebangau NP	5421.41	0.3	13
Tanjung Puting NP	4150.4	0.5	42
Kutai NP	1986.28	1.4	20
Gunung Palung NP	900.01	2.1	1
Danau Sentarum NP	1309.38	1.8	4
Betung Kerihun NP	8166.93	0.3	0

Sources:

KLHK, 2019. Statistik Lingkungan Hidup dan Kehutanan 2018. Sekretaris Jenderal KLHK, Republic of Indonesia.

KSDAE, 2018. Statistik Direktorat Jenderal Konservasi Sumber Daya Alam dan Ekosistem Tahun 2017. Kementerian Lingkungan Hidup dan Kehutanan, Direktorat Jenderal Konservasi Sumber Daya Alam dan Ekosistem, Republic of Indonesia.

PHKA, 2015. Statistik Direktorat Jenderal 2014. Sekretariat Direktorat Jenderal Perlindungan Hutan dan Konservasi Alam, Republic of Indonesia.

^a Hectares forested estate include kawasan konservasi, Hutan Lindung (HL), Hutan Produksi Terbatas (HPT), Hutan Produksi Tetap (HP), and Hutan Produksi yang Dapat Dikonversi (PHKA 2015).

^b Enforcement officers include all police officer (*Polhut*) and natural resource protection officers (PPNS), excepting *Polhut* trainees. Annual reports indicate enforcement officer numbers have been relatively stable since 2009 (PHKA 2015; KLHK 2019).

^c Total crimes are all crime types found in this study for years 2007–2019.

^d National Parks enforcement officers are police officers (*Polhut*) assigned to the parks (KSDAE 2018).

the opening of two rescue centers in the province, one in the western coastal region which began accepting animals in 2009 and the other in the north central region in 2010 (Knott et al., 2021).

4.2. Detection rates of orangutan crimes

All the Indonesian national parks with orangutans have government enforcement officer levels below the 3–11 officers/100 km² that is considered global best practice for effective protected area management (Bruner et al., 2001), and to address poaching of targeted species (Henson et al., 2016). Unprotected areas, which have the highest number of crimes overall (Table A9), do not have dedicated government enforcement officers but are served by provincial enforcement staff

(Table 1).

Orangutan population viability assessment indicates that hunting mortality of 1 % of adults in suboptimal habitat or 2 % of adults in optimal habitats will likely lead to extinction (Marshall et al., 2009). The estimated orangutan mortality would meet or exceed the 1 % mortality threshold at all detection rates of 10 % or less in all habitats within the latest time period (Table 2). Even at an optimistic 10 % detection rate, the killing rates in East and West Kalimantan in the most recent time period would be expected to drive populations to extinction even in the highest quality habitats (Husson et al., 2009). In Sumatra, the killing rate would be three times this threshold even at a 10 % detection rate. During the most recent time period, mortality rates in Sumatra would drive populations to extinction in suboptimal habitats even under an aspirational 24 % detection rate.

Clustering of reported crimes in and around protected areas and conservation activity areas may reflect the greater presence of enforcement personnel, researchers, NGOs, and engaged community members in these areas (Figs. 2 and 3), as well as higher orangutan densities. Most of the crimes in our dataset (67 %) were illegal pets or orangutans captured due to conflict. This suggests detection efforts are more successful in identifying crimes of orangutan possession and trade, but less so in finding killing and capture of orangutans. These crimes are much more difficult to detect, as they require intercepting poaching or capture or finding evidence of it in the animals' home range. Analysis of orangutan poaching rates using occupancy models to account for imperfect detection and reporting errors (e.g. Barber-Meyer, 2010) would be useful if data on ranger patrol and monitoring effort, orangutan surveys and information on orangutan sightings are available, although the lack of data from remote areas of orangutan distribution means there may still be a bias towards crime detection and occurrence in conservation activity centers and urban areas where illegal pet owners are apprehended.

NGO involvement in improved detection is crucial, as their personnel appeared to detect nearly all of the orangutan crimes apprehended in Indonesia during this study. NGOs provide resources to support patrols including funding, patrol posts, and personnel (Table A5) and operate "tip lines", where people can call in to report orangutan conflict or crimes, and informal information gathering networks to identify illegally held orangutans.

4.3. Efforts to address orangutan crime

The laissez-faire law enforcement of orangutan crimes in Indonesia may stem from the government's publicly-stated position that orangutan populations are not in decline and will not go extinct (Foresthints, 2020), contrary to peer-reviewed science indicating that populations of all three species are in decline (Meijaard et al., 2018). There is also a strong government focus on reconciling wildlife conservation with sustainable development and poverty alleviation goals, and a concomitant reluctance to punish rural community members (Wiratno, 2018).

The fact that we only found 21 court cases since 2007 that resulted in successful convictions, and that there were instances of repeat offenders and lack of remorse over being caught (Rainer et al., 2020; Sherman et al., 2020), suggest that perpetrators are confident that their crimes will not be detected or punished, and that the benefits of illegal activity outweigh the risks. Confiscations and handovers of orangutans, accompanied by public education, have been conducted in Kalimantan and Sumatra since 1971 (Aveling and Mitchell, 1982). While this awareness raising has presumably contributed to the broad public knowledge of orangutan protection laws, it has not appeared to decrease crimes, which have remained common, and are very rarely prosecuted (Nijman, 2017). This is a remarkably lax enforcement approach compared with that for other iconic Indonesian species. For example, over a ten year period, 619 crime investigations were conducted and 40 persons arrested for crimes affecting Sumatran tigers, with more than 90 % of the arrests leading to prosecutions (Risdiyanto et al., 2016).

Table 2
Estimated orangutan population mortality rates from illegal killing.

Province	Time period ^a	Approximate province level OU population ^b	Detected orangutan killings per time period ^c	Percent population mortality rate from illegal killing at global wildlife and environmental crime detection rates ^d					
				1.2 % ^e	3.2 % ^f	6.2 % ^g	10.0 % ^h	24.0 % ⁱ	70.0 % ⁱ
Central Kalimantan	2007–2010	86,800	192	18.4 %	6.9 %	3.6 %	2.2 %	0.9 %	0.3 %
	2011–2013	75,600	104	11.5 %	4.3 %	2.2 %	1.4 %	0.6 %	0.2 %
	2014–2016	69,200	133	16.0 %	6.0 %	3.1 %	1.9 %	0.8 %	0.3 %
	2017–2019	60,400	64	8.8 %	3.3 %	1.7 %	1.1 %	0.4 %	0.2 %
East Kalimantan	2007–2010	30,400	39	10.7 %	4.0 %	2.1 %	1.3 %	0.5 %	0.2 %
	2011–2013	26,900	50	15.5 %	5.8 %	1.0 %	1.9 %	0.8 %	0.3 %
	2014–2016	25,400	27	8.9 %	3.3 %	3.5 %	1.1 %	0.4 %	0.2 %
	2017–2019	22,800	30	11.0 %	4.1 %	1.4 %	1.3 %	0.5 %	0.2 %
West Kalimantan	2007–2010	46,500	41	7.3 %	2.8 %	1.4 %	0.9 %	0.4 %	0.1 %
	2011–2013	41,200	43	8.7 %	3.3 %	1.7 %	1.0 %	0.4 %	0.1 %
	2014–2016	37,200	81	18.1 %	6.8 %	3.5 %	2.2 %	0.9 %	0.3 %
	2017–2019	32,500	38	9.7 %	3.7 %	1.9 %	1.2 %	0.5 %	0.2 %
Sumatra	2014–2016	14,600	48	27.4 %	10.3 %	5.3 %	3.3 %	1.4 %	0.5 %

^a The first time period in Kalimantan includes an additional year to enable direct comparison among all subsequent three year time periods. A single time period is used for Sumatra as population estimates for other time periods were not available.

^b Kalimantan populations calculated from Voigt et al. (2018) and rounded to the nearest hundred. Sumatra populations of *P. abelii* and *P. tapanuliensis* combined from Wich et al. (2016).

^c Killing numbers are the subset of lethal crimes reported or calculated for provinces in orangutan species distribution and where orangutans have been reintroduced. Excludes 30 killings of Bornean orangutans and 13 killings of Sumatran orangutans detected in locations outside species distribution and reintroduction site provinces.

^d Percent mortality (detected killings × detection rate/100)/estimated OU population.

^e Based on undercover infiltration of United States poaching groups (Beattie et al., 1977; Kaminsky, 1974).

^f Estimate based on wildlife crime analyses of illegal logging in Papua, Indonesia (Akella and Cannon, 2004).

^g Estimate based on wildlife crime analyses of illegal fishing in Philippines (Akella and Cannon, 2004).

^h No methodology provided; estimate of maximum possible detection rate for wildlife crime in Cambodia (Claridge et al., 2005).

ⁱ Model of predicted snares that would be encountered by ranger patrols in Sumatran national park (Linkie et al., 2015).

Indonesian leopard crimes had a 48.8 % prosecution rate for 41 seizure records (Gomez and Shepherd, 2021). These rates, while insufficient to address big cat trafficking, are nonetheless much higher than for orangutan crimes. The accepted paradigm of consequence-free seizures and handovers of orangutans, with general education as a stand-in for strategic demand reduction, has long proven insufficient to address rampant crime, and its continuance presages a bleak future for the species.

Investigative and prosecutorial support of government law enforcement has helped to advance some cases in West Kalimantan (Freund et al., 2017; Knott et al., 2021) and in Sumatra (authors' unpublished data). Several of the successful convictions reported here (Table A8) were obtained following both investigative support and long-term media and public pressure campaigns by NGOs, notably rescue centers and wildlife crime investigation organizations (COP, 2021; Freund et al., 2017).

Crimes of trafficking and killing prosecuted during the study period typically resulted in light sentences, such as six months jail time and a 500,000 IDR fine (US\$ 35) (Table A8). The government generally does not pursue any legal action if people are willing to surrender the animals (Nijman, 2017), and NGOs and officials have expressed reluctance to take legal action against local community members. High ranking government officials who illegally keep orangutans have likewise not been successfully prosecuted (Karokaro and Hanafiah, 2019). The reluctance to prosecute local orangutan owners does not appear to apply to other species or situations. For example, local villagers have been prosecuted for crimes affecting tigers (Risdiyanto et al., 2016) and for illegal logging (SOS, 2021).

Deterrent effects of consistent researcher and monitor presence may partly account for low incidence of crimes in long-term research sites (Figs. A3, A4). Crime rates declined in sites where a combined approach addressed conservation education, long-term community development and alternative livelihoods initiatives, and anti-poaching patrols or community forest monitoring in targeted areas where communities had issues with local orangutan populations (Figs. A3 and A4). These

activities, along with incentivizing forest protection, successfully protect orangutan habitat in Gunung Palung National Park (Jones et al., 2020).

Over the past few decades, government and NGOs have aimed to avoid orangutan crimes by capturing and translocating animals away from potential conflict. Public messaging is focused on alerting authorities or NGOs whenever an orangutan is sighted near homes or crops (Sherman et al., 2020). Most people want the animals translocated elsewhere, a request that NGOs and authorities typically accommodate (Jaya, unpublished data). While this may prevent additional crimes, many translocated individuals in this study were already victims of crimes, including injury by bullets or machetes. Additionally, translocated orangutans often returned to capture sites (Sherman et al., 2021), meaning their removals were not successful for orangutans or humans, and may cause significant conservation harm to orangutan metapopulations (Ancrenaz et al., 2021).

5. Recommendations

Much expanded and strengthened efforts on crime deterrence and law enforcement are urgently needed. Locally adapted Situational Crime Prevention (SCP) frameworks can be used to improve detection and enforcement while addressing local community needs. SCP employs diverse interventions to render crime more difficult, less rewarding, and riskier, while simultaneously addressing triggers such as human-wildlife conflict, and eliminating justifications for conducting crime (Kurland et al., 2017). Targeted SCP frameworks focusing on local community-identified needs may help address social concerns related to wildlife protection laws, such as the perceived fairness of the treatment of wildlife versus local people (Travers et al., 2019).

We recommend immediate implementation of:

1. Increased government buy-in for law enforcement

It is crucial that the government is informed about currently unsustainable crime and killing rates and the need for stronger enforcement.

Without understanding of crime and lack of enforcement as a key threat to orangutans, none of the recommendations below are likely to be accepted. Scientists, NGOs, local citizens, and the media play key roles in informing and engaging the government and the public about orangutan crimes.

2. Strengthened and expanded patrols

Strengthened detection and deterrence through significant expansion of effectively planned and implemented SMART patrol capacity across orangutan habitats in both formally protected and unprotected habitats is crucial. Enforcement effort for all protected areas of all types—not just national parks—in orangutan distribution should be increased to at least 3 officers per 100 km² (Table 2), with sufficient patrol personnel to routinely cover all accessible areas of orangutan habitat. Patrols should be planned such that locations are sufficiently random to avoid being predictable to poachers.

The designation of selected non-government patrol personnel to supplement limited government capacity and budgets, as is done in Kerinci Seblat National Park in Sumatra and in Sabah, Malaysia, could improve enforcement capacity in Indonesian orangutan distribution. Honorary Wildlife Wardens in Malaysia are granted arrest authorities similar to government personnel (Sabah, 1997). Kerinci Seblat National Park ranger patrol units work with community members who are honorary park officers, and the units have authority to make arrests if other authorities cannot be present (Linkie et al., 2015). These ranger units manage a network of local community informants whose assistance significantly increased detection likelihood. The Kerinci Seblat informants are offered random, small incentives to build loyalty while avoiding false reporting.

Patrol coverage on unprotected lands should be dramatically increased to reach three patrol officers or monitors per 100 km². Patrolling of all forested lands within Tapanuli orangutan habitat is a priority, and patrolling of forests in agricultural, logging and mining estates and community lands is an urgent need for Sumatran and Bornean orangutans.

3. Investigation of all crimes and enforcement of wildlife laws

All illegal clearing of orangutan habitat, and harm, capture, killing, trade, or possession of orangutans should be investigated, perpetrators apprehended and prosecuted, and any consequences publicized widely to establish deterrence.

NGO support for investigation is important at least until government capacity is increased. Investigation teams with dedicated personnel that do not overlap with conflict response, community development, education, or other field teams are recommended to maintain trust of local community members.

4. Regular and fair sanctions and suitable regulation

Well-trained judiciaries, prosecutors, and police that appreciate the seriousness of wildlife crime and the full complement of applicable laws for its prosecution are critical. Rational sentencing guidelines are needed to address disparities of intent, circumstance, and income of law breakers to avoid unintended consequences, notably the perception that orangutans are more valued than people (Beech, 2019; Chua et al., 2021). This may require additional knowledge and capacity building around the importance of prosecuting wildlife crime and developing targeted sentencing guidelines.

Orangutan killing, sale, and clearcutting of identified orangutan habitat should be treated as serious crimes. Prosecutions for these crimes can be based on laws beyond species protection, including weapons possession, customs law, tax evasion, and animal welfare (Nijman, 2017). Sanctions should be stiffest for politicians, military, and other civil servants breaking the laws they are sworn to uphold, and for

companies and management level employers who encourage or disregard intentional orangutan killing or habitat clearance, while those for workers paid to target the animals, or for local villagers who capture orangutans opportunistically could be more lenient. The surety of consequences—the application of even minor sanctions consistently—is more important than handing out stiff penalties particularly to impoverished villagers.

Surrender or seizure of illegally held orangutans should be directly tied to investigations to identify poachers, sellers, and those keeping the animals as pets. People who find or are given infant orangutans and promptly report the situation to rescue centers or authorities should not face penalties, but those who intentionally keep or sell the orangutans are committing a crime. Although arresting every pet owner is politically impractical and may create heightened animosity towards orangutans, even a small number of well-publicized convictions for illegal orangutan possession may improve deterrence. At a minimum, every person surrendering an orangutan should have to sign a formal declaration to the government admitting the criminal action and acknowledging that any subsequent infractions will result in arrest. Repeat offenders should be arrested and sanctioned.

New regulations may be needed for hunting practices that unintentionally target orangutans, such as prohibitions on snaring in protected orangutan habitats.

5. Community engagement

Strategies targeted to local needs are required to change local perceptions of orangutans, as well as hunting and land management practices (Chua et al., 2021; Jones et al., 2020; Maskulino et al., 2021). Long-term engagement with local communities, characterized by an ethnographic focus of understanding people's lives and interests, is necessary to empower communities as equal partners and identify interventions that will effectively change illegal behaviors and incentivize orangutan conservation. Funders should support long-term community engagement, along with monitoring of implemented projects' effects on human wellbeing and orangutan conservation.

6. Incentivizing positive behavior change

Results from community engagement efforts should be used to build locally specific strategies that address identified livelihood and community needs. Community and traditional land rights are a vital element. Community agreements or customary laws prohibiting orangutan hunting, or forgoing snaring and tree-cutting in certain areas, can be helpful. Benefit sharing and other compensations or direct benefits may be required to offset crop losses, address livelihoods lost to restricted hunting and trading, or meet community development needs in exchange for compliance with orangutan protection measures. Examples include long-term employment opportunities in research and ecotourism, provision of health care services and payments for retirement of chainsaws and guns (Jones et al., 2020), and community land rights coupled with forest management plans (Knott et al., 2021). Rescue centers, research centers, and other local NGOs lead these efforts.

Community members should be trained and deployed as orangutan monitors in known conflict areas, particularly protected area buffer zones and unprotected areas in Kalimantan and Sumatra. Their monitoring mission would be protecting local orangutans from harm, and defusing conflict without translocating the animals. Public messaging about orangutans near human use areas should not offer the animals' removal but instead should inform people to keep their distance and leave the protected animals unharmed.

7. Monitoring and evaluation of deterrence interventions

All crime deterrence interventions should be systematically monitored and evaluated, and results should inform modifications to avoid

spending limited conservation funding and effort on well-intentioned yet ineffectual actions. Conservation funders should require and finance monitoring, as lack of funding for these activities is a barrier for practitioners.

6. Conclusion

Our study demonstrates that reported orangutan crimes continue at rates likely to far exceed the 1–2 % offtake of adults predicted to drive populations to extinction, and indeed recent studies show all orangutan species have declined dramatically in the past decade (Santika et al., 2022). Anti-poaching patrols and community monitors need to be dramatically expanded across protected and unprotected areas. Criminal investigation of all crimes and regular application of sanctions for law-breaking should be the norm. Conservation and community development interventions targeted to local needs while protecting wild orangutans and their habitats should be implemented, monitored, and evaluated, and successful practices scaled up to forestall further crimes. These lessons are applicable to many biodiverse tropical landscapes struggling with wildlife crime.

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CRediT authorship contribution statement

Julie Sherman: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, visualization, writing–original draft, review & editing. Maria Voigt: formal analysis, methodology, visualization, writing–review & editing. Marc Ancrenaz and Serge A. Wich: conceptualization, methodology, writing–review & editing. Erica Lyman and Emily Massingham: conceptualization, writing–review & editing. Indira N. Qomariah: investigation, writing–review & editing. Erik Meijaard: conceptualization, investigation, methodology, writing–review & editing.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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