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Asian elephants in Cambodia: a comprehensive national assessment of conservation status, distribution, threats and negative human–elephant interactions

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Asian elephants in Cambodia: a comprehensive national assessment of conservation status, distribution, threats and negative human–elephant interactions

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Abstract

Balancing the needs of people and wildlife in multi-use landscapes is often hindered by limited socio-ecological information. To guide future conservation and sustainable management planning, this study used a multifaceted approach to assess Asian elephant status, threats, management efficacy, and negative human-elephant interactions (NHEIs) across Cambodia by integrating a literature review, stakeholder data requests, questionnaires, field surveys and multi-stakeholder workshops. Results indicate that elephants predominately occur within protected areas (PAs), although their national range has contracted. Confirmed populations currently exist in 18 PAs, including three where elephants reappeared after over a decade's absence, while 10 PAs (one degazetted) no longer support populations. We estimate that Cambodia supports between 747–899 wild elephants, and 67 captive individuals. The largest populations occur in the east (mean estimates:

Phnom Prich, 185; Srepok, 162; and Keo Seima, 116) and are the most genetically diverse. The next largest population is in the southwest (Cardamoms and Tatai; 45–120 individuals) and exhibited comparatively low mitochondrial diversity. Most remaining populations are small (<45 individuals) and predominantly isolated, but often data deficient. Snaring, alongside habitat loss and fragmentation, were identified as the current primary threats. However, perceived effectiveness of current conservation interventions varied. NHEIs appeared to be increasing in spatial extent, with 13 PAs and one district outside of PAs recording incidents between 2018 and 2023, and the effectiveness of mitigation measures varied. These findings can be used to prioritise interdisciplinary strategies and research gaps to conserve vulnerable populations while improving the wellbeing of residents impacted by elephants.

Key Words: *Elephas maximus*, Nationwide survey, Multi-stakeholder engagement, Population size, Genetic diversity, Range contraction

Introduction

Effective conservation planning and action depend on robust information about species' population status, trends, distribution, and threats (Nichols and Williams 2006; de Silva 2016; Struebig et al. 2025), especially within shared human-dominated landscapes. Southeast Asia is densely populated and experiencing extensive anthropogenic modification yet also harbours some of the world's most threatened megafauna, including wide-ranging species such as elephants, presenting a significant conservation challenge for maintaining viable wildlife populations (Sodhi et al. 2004; Hughes 2017; Mahmood et al. 2021; Xu et al. 2024; Struebig et al. 2025). Most populations of the globally endangered Asian elephant (*Elephas maximus*) have undergone numeric declines and range contraction, driven primarily by development (habitat modification and expanding infrastructure), hunting (live capture or product trading), and escalating negative human–elephant interactions (NHEIs) (Menon and Tiwari 2019; Prakash et al. 2020a; Mahmood et al. 2021; de Silva et al. 2023; Xu et al. 2024). Habitat modification, combined with increasing anthropogenic pressures, can exacerbate NHEIs (Anuradha et al. 2019; Puyravaud et al. 2019; Ram et al. 2021; Gunawansa et al. 2023), necessitating integrated approaches that support both elephant conservation and human wellbeing.

Despite the urgent need for evidence-based action, obtaining reliable site and national-scale data on Asian elephant populations remains challenging. Early range-wide syntheses highlighted major data deficiencies in fundamental population parameters, often relying on expert judgement rather than estimates from scientific surveys (Duckworth and Hedges 1998;

Sukumar 2003; Blake and Hedges 2004; Hedges et al. 2005). Although published research output continues to increase, persistent gaps in knowledge continue to constrain conservation planning and practice (de Silva 2016; Zakaria et al. 2024).

In Cambodia, available information indicates substantial declines over the last five decades, from speculative estimates of ~10,000 elephants in the 1960s–1970s (Olivier 1978) to ~2000 by the 1980s (Santiapillai and Jackson 1990). The latest estimate presented in the National Elephant Action Plan synthesised published studies (Pollard et al. 2008; Maltby and Bourchier 2011; Gray et al. 2014) and anecdotal reports, estimating that only 400–600 wild elephants remain in fragmented populations of 10–150 individuals (GDANCP 2020). However, these figures remain subject to substantial uncertainty, persistent data gaps and predate recent site-based estimates by Sinovas et al. (2025) and Crouthers *et al.,* (2026a).

A range of anthropogenic threats (hunting, live capture, and war) are thought to have declined following strengthened legislation and enforcement (Maltby and Bourchier 2011; GDANCP 2020), while other anthropogenic pressures appear to be intensifying. Cambodia is reported to have one of the highest levels of habitat loss globally (Imai et al. 2018; Namkhan et al. 2021; Wolf et al. 2021) and ranks among the top five southeast Asian countries for projected forest loss (Estoque et al. 2019), with 23.2% of forest cover within known elephant ranges converted between 2001 and 2018 (Luo et al. 2022). Agricultural expansion, urbanisation, and extension of roads and electrical networks continue to deplete elephant habitat (Davis et al. 2015; Grogan et al. 2019; Kong et al. 2019; Tsujino et al. 2019; Magliocca et al. 2020; Luo et al. 2022) both within and beyond protected areas (PAs), and NHEIs, perhaps exacerbated by habitat loss and fragmentation, occur across Cambodia (Webber et al. 2011), with recent localised increases reported (GDANCP 2020; English and Collins 2022). Pairing robust high-resolution national data on elephant population status with an empirical evaluation of current and changing threats, including NHEIs, alongside an evaluation of conservation governance, would assist conservation planning and action, but remain logistically and financially challenging to obtain.

Cambodia's PA legislation and governance are continually evolving, most recently through the consolidation of PA management under the Ministry of Environment (MoE) in 2016 and, in 2023, revisions to the PA network and adoption of the Code on Environment and Natural Resources. As of 2023, 68 terrestrial protected areas (PAs) covered ~6.9 million hectares, representing ~39% of the national land area (Crouthers 2024). The 2023 Code superseded the 2008 Law on Protected Areas, but retains a similar framework of four management zones, ranging from strict biodiversity protection to social, cultural and economic land uses. However, formal zonation remains absent from most PAs, largely due to resource constraints (Crouthers 2024), presenting ongoing challenges for effective management and land-use regulation. Thus,

population status and threat assessments might also inform the design and strengthening of legal frameworks for population and habitat protections.

Collaborative approaches that integrate ecological data, expert knowledge, and stakeholder perspectives are increasingly used to address population and threat knowledge gaps and inform conservation priorities (Chen et al. 2021; Wong et al. 2021; Ladd et al. 2022; Tananantayot et al. 2022). Here, we present a national-scale, multifaceted and multi-stakeholder assessment of Asian elephants in Cambodia, integrating data on population size, trends, distribution, genetic diversity, threats, legal frameworks, NHEI occurrence, and mitigation measures. By combining ecological and stakeholder-derived evidence, this study aims to reduce critical knowledge gaps and strengthen evidence-based elephant conservation planning at both site and national scales.

Methods

This study comprised six phases conducted between 2019 and 2025 (Fig. 1).

Phase 1

Published and unpublished literature relating to Cambodian elephant population status (presence/absence, size, trends), distribution, genetic diversity, threats, legislation/management, NHEIs, and mitigation methods was reviewed (Fig. 1) to inform subsequent phases.

Phase 2

Wild elephant distribution was initially compiled from Phase 1 sources, including Duckworth and Hedges (1998), the 2008 IUCN elephant range-wide map produced by Hedges et al. (2009), Maltby and Bourchier (2011), and the National Elephant Action Plan (GDANCP 2020). See Online Resource 1 - Appendix 1 for details.

Stakeholders, including government agencies, conservation NGOs, and researchers, working within elephant range areas were identified. Conservation NGOs were consulted to identify relevant projects, assess data availability, and identify additional contributors. Requests for spatially explicit datasets relating to the Phase 1 themes were subsequently distributed to the MoE and identified stakeholders (Fig. 1). Where required, data-sharing agreements were established between the senior author (R.C.) and participating organisations.

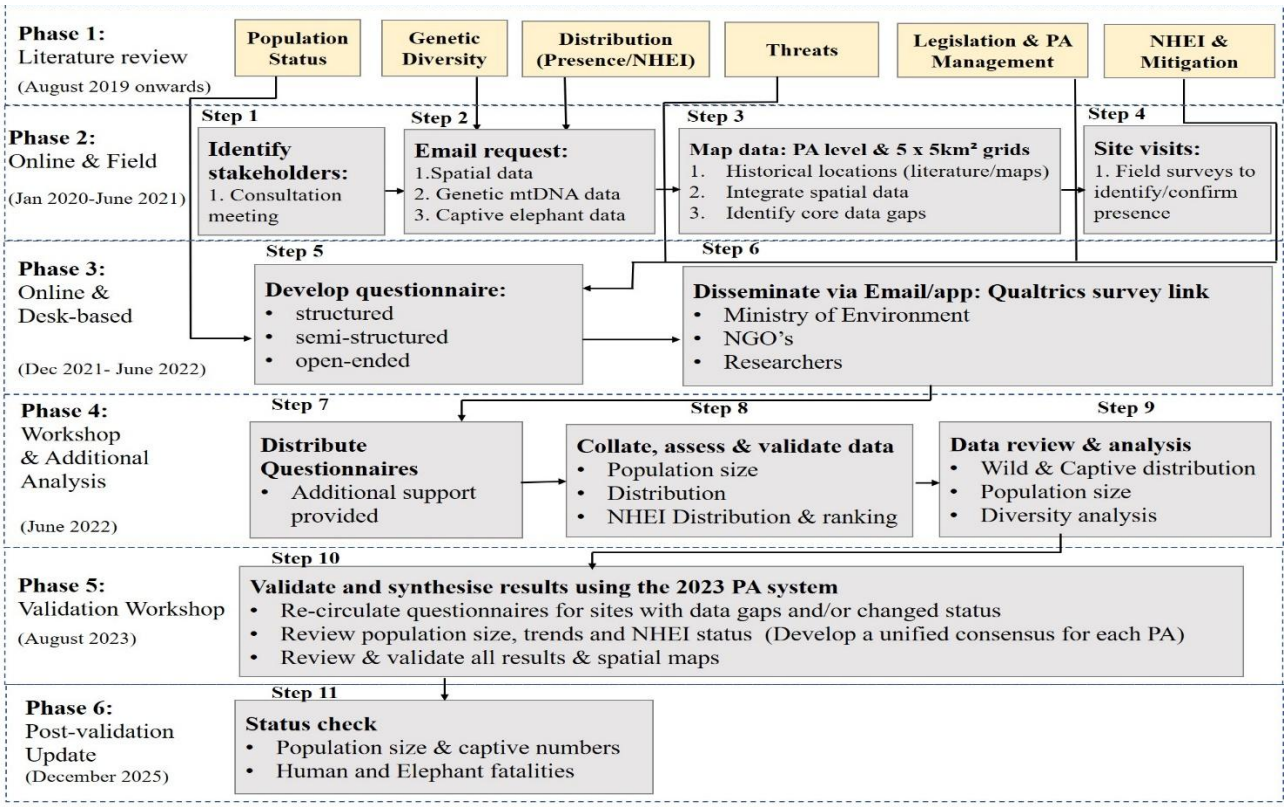


Fig. 1 Workflow for collating, consolidating, and validating data across six major themes in yellow (Population status, Genetic diversity, Distribution, Threats, Legislation/PA management, and negative human-elephant interactions [NHEIs]/Mitigation measures) for known or presumed elephant range sites across Cambodia

All spatial data were consolidated and standardised to World Geodetic System 1984 (WGS84; EPSG:32648) and mapped using QGIS 3.14 "Pi" (QGIS.org 2020). For data and species-sensitivity reasons, precise occurrence coordinates were not presented, except for the NHEI maps. Elephant occurrence was mapped at both PA and 5 × 5 km grid-cell scales, following the grid size adopted by Fernando et al. (2021). Available occurrence records/information, together with NHEI locations, were delineated into three timeframes: current (≥2010), historical-a (1997–2010), and historical-b (<1997), with records within each timeframe grouped as biodiversity/patrol, anecdotal, or historical literature. These data were then used to generate initial grid-cell maps for subsequent review.

PAs presumed to support elephants but lacking records since 2010 were classified as data deficient. Rapid assessments of selected data-deficient PAs, comprising field and interview surveys, were jointly conducted by R.C. and the MoE and, where applicable, the resident NGO (Fig. 1). Areas subject to rapid assessment were prioritised based on available data and consultations with relevant PA and/or NGO staff and then refined using indicators of presence.

Phase 3

A questionnaire was developed and implemented to obtain site-level information from practitioners and experts (Fig. 1), following the recommendations of Young et al. (2018). The questionnaire's design was informed by a review of previous Asian elephant and large mammal surveys to enhance comparability. The final questionnaire comprised seven sections to gather information on elephant presence, population size, non-natural deaths, threats, legislation/PA management, NHEIs, and deterrent/mitigation measures (Fig. 2).

The questions were developed in English and Khmer and administered using Qualtrics XM (Qualtrics 2023). Threat categories from the IUCN Threats Classification Scheme (v 3.3; www.iucnredlist.org/resources/threat-classification-scheme) were adapted and refined to reflect those most relevant to Cambodia (Fig. 2). Management and legislation questions focused on ranger numbers and the perceived effectiveness of current legislation/policy and PA management resources/effort, while the NHEI and mitigation sections aimed to gain a greater understanding of current status and trends (Fig. 2).

The questionnaire was piloted by experts in biological, sociological, and human-wildlife interaction research. The final questionnaire (Online Resource 2), together with the project description and consent form, received ethical approval from the Te Herenga Waka-Victoria University of Wellington Human Ethics Committee (Ref. 27101). Participation was voluntary and anonymous unless respondents chose to provide contact details, which remained confidential to the lead researcher and transcriber. The questionnaire was distributed via anonymous, reusable Qualtrics links by email or participants' preferred communication platforms. A "snowball sampling" approach (Naderifar et al. 2017) encouraged participants to share the questionnaire with their professional networks.

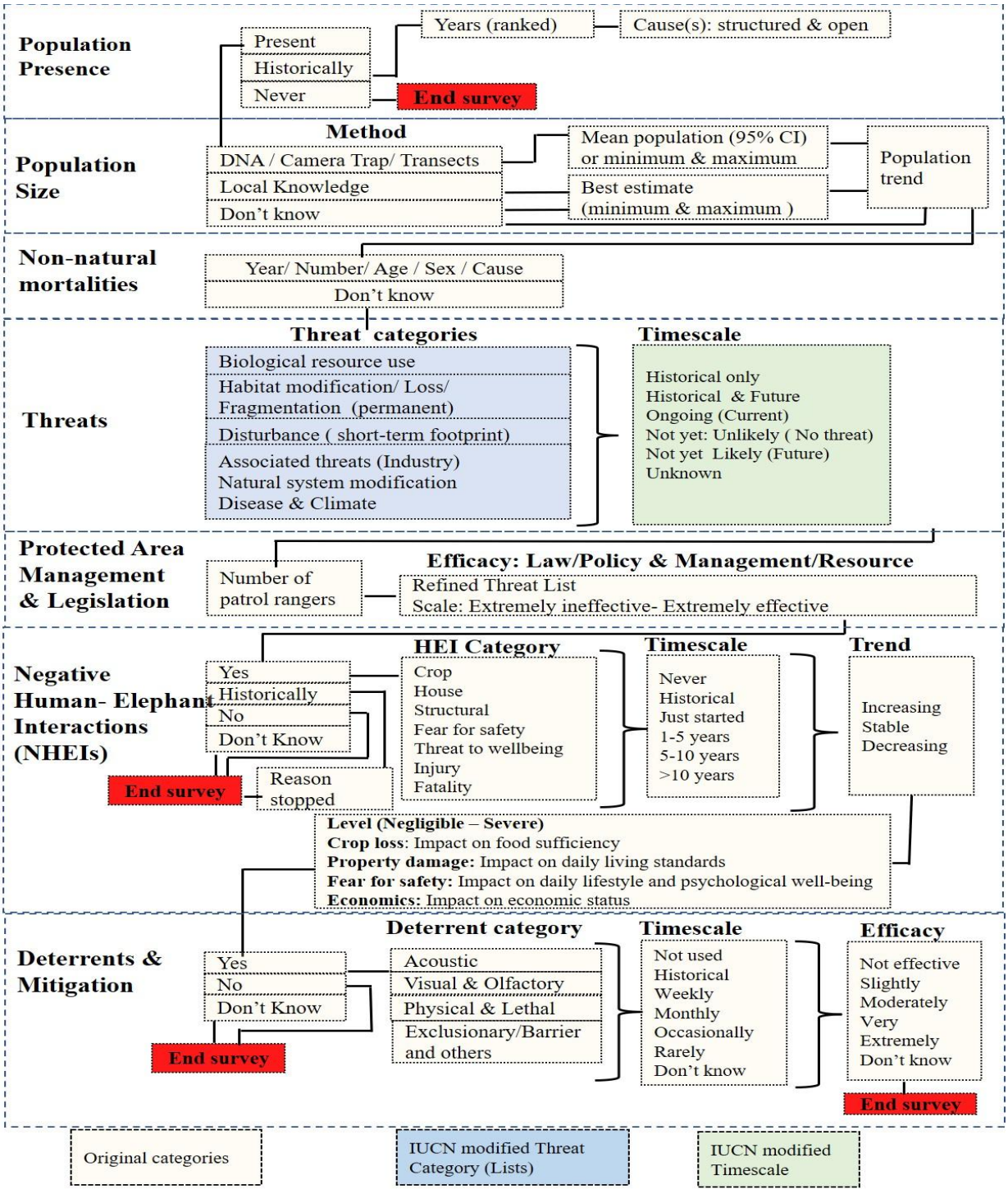


Fig. 2 Flow diagram depicting the questionnaire structure used to collect data across seven categories pertaining to Asian elephant status, threats, legislation/management, negative human-elephant interactions and mitigation/deterrent tools

Phase 4

A two-day National Elephant Workshop was held in 2022 to refine, consolidate, and validate population data and grid-cell maps of occurrence and NHEIs (Fig. 1). The questionnaire link was re-distributed to PA directors and staff in remote or resource-limited areas, with follow-up support provided where required. Participants requiring input from colleagues were asked to submit responses by September 2022.

During the mapping review, additional data were provided, and cells with known elephant presence but lacking spatial data were marked as anecdotal. Because of uncertainty in the timing of some older records and anecdotes, the two historical categories were subsequently combined. NHEI distribution maps were compiled from available spatial datasets. PAs lacking spatial data were included where sufficient corroborating evidence was available.

Population estimates and trends were reviewed, with scientific population estimates superseding anecdotal estimates. Where available, mean population estimates were used, followed by expert-derived minimum–maximum estimates for data-deficient or less-studied sites. To avoid double counting, joint estimates were used for sites with documented inter-PA movements, and transient seasonal groups were excluded. Population trends since 2010 were inferred from published estimates and/or expert assessments.

Post-workshop stakeholder consultations were conducted to review captive elephant locations and identify potential overlaps with wild elephants. Records outside the confirmed wild elephant range were excluded. Approximately ten captive elephants were reported to have entered three eastern PAs (Keo Seima, Phnom Prich and Srepok). Although some overlap with wild elephants may have occurred before 2015, extensive camera-trap and field datasets indicated the presence of large wild groups, reducing the likelihood of misclassification.

Mitochondrial DNA (mtDNA) sequences from uniquely identified wild elephants across eight Cambodian PAs were compiled from publications, publicly available reports, an unpublished dataset provided by Fauna & Flora/RZSS, and a PhD study (Online Resource 1 - Appendix 2). Sequence preparation, alignment, trimming and downstream analyses followed Crouthers et al. (2026b). Haplotype numbers, haplotype diversity (H_d) and nucleotide diversity (π) were calculated in DNASP v6.12.03 (Librado and Rozas 2009; Rozas et al. 2017). Cambodian sequences were aligned with the compiled global haplotype dataset of Crouthers et al. (2026b), using the same haplotype nomenclature to identify novel haplotypes, and assess regional differences in diversity, where applicable.

Phase 5

The final 2023 consultative validation workshop aimed to (1) validate the distribution maps, (2) review data using the new 2023 PA network, including changes in protection status, boundary expansions or mergers, integration of former biological conservation corridors, and PA establishment or degazettement. (3) establish a single consensus response per PA for the key themes among stakeholders (MoE and NGOs), and (4) update captive elephant numbers (Fig. 1). PAs are referred to by their commonly used names throughout; official names, designations, previous names and the identification numbers used in figures are provided in Online Resource 1 - Appendix 3. Questionnaire links were re-circulated for PAs with data gaps and/or reported changes in elephant presence (i.e. reappearance or absence). One PA (Snoul) that was degazetted was retained in descriptive tables and text as a historically occupied site but excluded from PA counts.

Questionnaire responses were divided into two datasets: unique responses (≥1 per PA) and, where available, a consensus response per PA. Government ranger densities were calculated using only government responses and re-verified with the MoE to reflect individual PAs rather than administrative provinces. Questions relating to threat impact and severity, and NHEI and mitigation scope and frequency, were excluded due to high data volume and complexity. Questionnaire data were analysed and visualised in R 4.2.1 (R Core Team 2022).

Final occurrence grids were classified as biodiversity/patrol, anecdotal field surveys, anecdotal workshops, or historical literature. For grid-cell analyses, records were consolidated into biodiversity/patrol and anecdotal categories for each timeframe. Where records overlapped biodiversity/patrol cells superseded anecdotal cells, due to their higher reliability. The remaining grid cells were used to calculate the area of current and historical distribution.

Phase 6

Additional meetings and targeted online searches were conducted to December 2025 to identify updates to wild elephant population estimates, captive numbers, and recorded elephant and human fatalities.

Results

Data compilation and completeness

The initial datasets were compiled from literature, stakeholder consultations and initial data contributions. Of the PAs considered to historically or currently support elephants, five were categorised as unknown presence/data-deficient and one (Siem Pang) was reported to lack presence data since 2015. Rapid assessments subsequently confirmed and mapped elephant presence in all five data-deficient PAs (Bokor, O'Yadav, Phnom Aural, Phnom Samkos and Samlaut). In Siem

177 Pang, however, no elephant signs were found during surveys, and interviews with communities and PA staff indicated no
178 presence since 2015, with the exception of an inaccessible military area that could not be assessed.

179 The 2022 National Elephant Workshop was attended by 91 participants (national government = 23, provincial
180 government = 47, NGO = 18, IUCN SSC members = 2, university = 1). By September 2022, 41 questionnaire responses had
181 been received, representing 25 PAs followed by additional questionnaire, spatial and anecdotal data in 2023.

182 The 2023 consultative validation workshop (47 participants: government = 32, NGO = 12 and IUCN SSC members
183 = 3) reviewed and validated the updated distribution maps and produced agreed consensus responses on population size,
184 trends, and NHEIs, though not on threats, PA management and mitigation themes. All data were re-reviewed in September
185 2023, and earlier responses for any PA with revised elephant status (from historical to current) were discarded. Of the 48
186 questionnaires received, 44 were retained for final analyses (government = 22, NGO/researcher = 21, joint government-NGO
187 = 1), alongside the final compilation of spatial data from primary sources, as well as MoE, ten NGOs and three independent
188 researchers.

189 **Elephant presence and distribution**

190 Based on the 2023 PA network, and with spatial data superseding anecdotes, elephants were known or presumed to
191 occur in 28 currently recognised PAs, equivalent to 31 PAs under the previous 2018 network. Differences reflect the
192 degazettement of Snoul, the merger of Chhaeb and Preah Roka into Chhaeb-Preah Roka Wildlife Sanctuary, and the
193 consolidation of Central and Southern Cardamom Mountains National Parks into Phnom Kravanh National Park, commonly
194 known as the Cardamoms and referred to as such hereafter.

195 ***Historical presence and distribution***

196 Of the PAs initially identified as no longer supporting elephants, ten (including the degazetted Snoul) were
197 confirmed as devoid of elephants based on historical spatial data, the absence of post-2010 records, questionnaires, and
198 workshop reports (southwest = 2; central/northern = 6; northeastern = 1; east = 1; Fig. 3). Reasons for local absence varied,
199 with war, civil unrest, targeted hunting, live capture, and habitat modification and/or disturbance the most frequently cited
200 (see Online Resource 1 - Appendix 4 for PA-specific details). Although workshop participants generally considered these
201 populations locally extinct, they are classified here as historically occupied because recent reoccurrence has been confirmed
202 in other PAs.

After excluding overlapping anecdotal grid cells (n=4), historical elephant presence was identified in 651 cells (579 spatial, 72 anecdotal), covering 16,275 km² before 2010. Four PAs lacked useable location data: Beng Per, Phnom Kulen, Preah Sihanouk Ream and Veun Sai-Siem Pang (Fig. 3). Nonetheless, historical records or documentation combined with questionnaire surveys and anecdotal information suggested elephants previously occurred within these PAs.

Current presence and distribution

Current elephant presence was confirmed in 18 PAs (20 under the 2018 PA network), distributed across six spatially isolated regions (southwest = 8; central = 1; northwest = 1; north = 1; northeastern = 2; east = 5; Fig. 3). Confirmed reoccurrence after over a decade of absence was recorded in three PAs: O'Yadav in 2019, Banteay Chhmar Protected Landscape in 2022, and Lomphat in 2023. Possible but unconfirmed presence was reported in Phnom Namlear (Fig. 3; see Online Resource 1 - Appendix 5 for details). Comparisons with previous assessments revealed five major differences: O'Yadav and Banteay Chhmar changed from no historical records to confirmed presence; Bokor and Phnom Aural shifted from presence unknown to confirmed; and Lomphat from locally extirpated to confirmed presence.

Thirteen anecdotal grid cells overlapped with research cells and were thus excluded. Combined current and historical records indicate a contraction and spatial shift in distribution, with increasing fragmentation within and among several PAs (Fig. 3). Of the 651 historically occupied cells, 401 (10,025 km²) showed no evidence of presence since 2010. Current occurrence spans 491 cells (404 spatial, 87 anecdote), covering 12,275 km²; of which 250 (6,250 km²) overlap historical range, and 241 (6,025 km²) represent newly documented or previously unrecorded areas (Fig. 3). Elephant occurrence is predominantly concentrated within PAs, 486 of 491 cells (99%) situated within or bordering PA boundaries, although fragmentation and isolation are evident across most regions (Fig. 3). Regional-specific summaries are provided below with additional details in Online Resource 1 - Appendix 6.

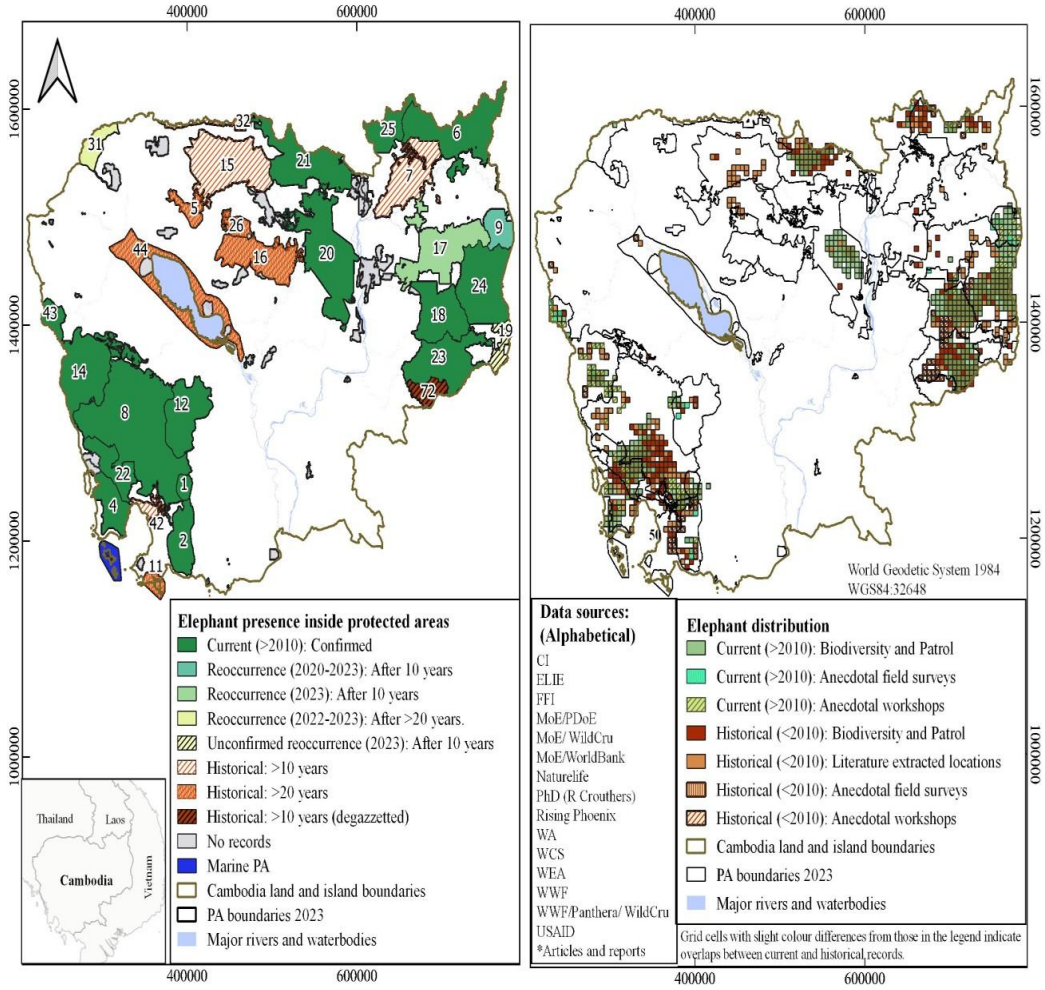
Most southwestern populations are now highly fragmented, with two considered isolated from other Cambodian populations: (1) Bokor, following major road development between Bokor and Kirirom, and (2) Samlaut, although it may form part of a larger transboundary population with Thailand (Fig. 3; Online Resource 1 - Appendix 6). Camera trap surveys confirmed elephant movement between the Cardamoms and Tatai; however, despite unconfirmed potential movement across other PA boundaries, the remaining populations were generally considered functionally isolated (Fig. 3; Online Resource 1 - Appendix 6). In central and northern Cambodia, the two remaining populations in Chhaeb-Preah Roka and Prey Lang are considered isolated following extensive habitat modification and fragmentation over the past 30 years (Fig. 3; Online Resource 1 - Appendix 6). In the northeast, distribution was restricted to Virachey and Siem Pang, where records remained

sparse. No confirmed elephant records were obtained from Siem Pang after 2015 despite additional rapid assessments, although a few reports suggested possible persistence within an inaccessible military concession in the northeastern section of the PA (Fig. 3; Online Resource 1 - Appendix 6). In the east, recent distributional changes included reoccurrence in O'Yadav and Lomphat (Fig. 3), suggested to coincide with habitat modification and increasing anthropogenic pressure in Cambodia and Vietnam. Workshop discussions suggested that movement between Keo Seima and Phnom Prich had ceased, primarily due to habitat modification and disturbance within former economic land concessions and settlement expansion along connecting roads. Restricted movement within Srepok was attributed to National Road 76 upgrades and mining exploration concessions, while movement between remaining PAs likely occurs (Fig. 3; Online Resource 1 - Appendix 6).

Population estimates and trends

The national population was estimated at 747–899 wild elephants, using mean values from scientific surveys and minimum–maximum expert estimates for all other sites (excluding transient individuals in Lomphat). The three largest populations occur in the east (Fig. 3), with mean estimates derived from faecal DNA capture-mark-recapture (CMR) surveys: Keo Seima (116; Pollard et al. 2008), and Phnom Prich and Srepok (185; 162; Crouthers et al. 2026a). The next largest population (45–120 individuals) occurs across two connected western PAs (Cardamoms and Tatai; Fig. 3), with estimates derived from expert opinion together with published and/or unpublished camera-trap and genetic data. The remaining 13 PA populations were small, with estimates ranging from <10 to 41 individuals (Fig. 3). Two mean population estimates were derived from DNA CMR surveys (Prey Lang = 31; Chhaeb-Preah Roka = 20; Sinovas et al. 2025), whereas the remaining 11 were based on expert opinion (Fig. 3).

Elephant populations were believed to have declined substantially prior to and during the American-Vietnam War and Cambodian Civil War. Reported drivers included targeted hunting (for sport, products, and consumption), live capture, and war-related mortality and disturbance (e.g. targeted and indirect shooting, bombs and land mines). Despite these historical declines, 15 of the 16 extant resident PA populations were perceived to be stable or increasing since 2010 (Fig. 3). Trends were classified as unknown for Lomphat and Banteay Chhmar as both populations were only recently re-established and absence of monitoring precludes assessment (Fig. 3). Workshop participants considered the Lomphat elephants to be a transient group from neighbouring Phnom Prich, whereas Banteay Chhmar likely supports a seasonally connected transboundary population.



ID	Protected Area	Population Estimates	Perceived Trend (10 years)
Current			
1.	Kirirom	7-10	Increasing
2.	Bokor	10-25	Increasing
4.	Botum Sakor	25-30	Increasing
6.	Virachey	30-35	Increasing
8.&22	Cardamons & Tatai	45-120	Stable
12.	Phnom Aural	20-35	Increasing
14.	Phnom Samkos	30-40	Increasing
18.	Phnom Prich	185 (128-301) [1]	Stable
20.	Prey Lang	31 (24-41) [2]	Increasing
21.	Chhaeb-Preah Roka	20 (13-22) [2]	Stable
23.	Keo Seima	116 (101-139) [3]	Stable
24.	Srepok	162 (108-281) [1]	Stable
25.	Siem Pang	<20	Decreasing
43.	Samlaut	20-25	Stable
Reoccurrence			
9.	O'Yadav	20-35	Increasing
31.	Banteay Chhmar	< 10 (6)	Unknown
17.	Lomphat	<10 (4)	Unknown
19.	Phnom Namlear	No data	No data
Historical			
5	Phnom Kulen	-	-
7	Veun Sai-Siem Pang	-	-
11	Preah Sihanouk Ream	-	-
15	Kulen Promtep	-	-
16	Beng Per	-	-
26	Phnom Thnout- Phnom Pok	-	-
32	Preah Vihear	-	-
42	Dong Peng	-	-
44	Tonle Sap	-	-
72	Snoul (degazzetted)	-	-

Fig. 3 Current and historical elephant presence for all revised protected areas (PAs) in Cambodia with associated information of status, estimated population size and perceived trends. Historic and current presence are presented at PA level (a) and 5 × 5 km grids (b). Of the 18 PAs with confirmed current presence, population estimates for 13 PAs are based on expert opinion, and five are produced using CMR models from faecal DNA surveys ([1]Crouthers et al. 2026a, [2]Sinovas et al. 2025, [3]Pollard et al. 2008)

Captive population

Based on data from August 2023, 73 captive elephants were owned by individuals, families, and/or organisations, with most beyond reproductive age. Approximately twenty-three were believed to kept in institutional or confined facilities within the capital, while the remainder were distributed across four provinces: Mondulkiri (n=26), Siem Reap (n=19), Ratanakiri (n=4) and Kampong Cham (n=1). Between the 2023 assessment and December 2025, four additional young elephants entered captivity in Phnom Penh (two gifts and two rescues), while an estimated ten deaths occurred (most attributed to old age, one juvenile with suspected elephant endotheliotropic herpesvirus). The most recent estimate is therefore 67 captive elephants.

Workshop discussions further confirmed that captive elephant breeding within some Indigenous communities is generally considered culturally inappropriate or taboo, particularly among the Bunong of Mondulkiri. As such, intentional breeding of family-owned captive elephants is rare. In 2021, an unintentional conception between a captive female and a wild bull was reported and met with negative community perceptions. To mitigate the perceived adverse consequences associated with this event, a series of ceremonies were held both prior to and after the birth.

Genetic diversity in Cambodia

The initial Cambodian mtDNA dataset comprised 232 individuals from eight PAs. After quality control, 210 sequences from six PAs were retained, with exclusions due to potential individual overlap, insufficient sample size, sequence overlap, or uncertain PA attribution (details in Online Resource 1 - Appendix 2). Sequences from five PAs were aligned to a 152 bp fragment, whereas the Cardamom population sequences (148 bp; n=43) lacked overlap at 49 nucleotide positions with the other populations. Haplotype analyses were therefore conducted using two alignments: (1) a 152 bp fragment for five PAs (n=167) and (2) a matching 103 bp fragment for six PAs (n=210) (Table 1).

Table 1 MtDNA analysis of unique wild elephants in Cambodia using the two sequence alignments, number of protected areas (PAs), number of wild unique individuals (n), number of haplotypes (H), haplotype diversity (*H*d), nucleotide diversity (π), average number of nucleotide differences (k) and Haplotype identifier labels

Sequence	PAs	n	H	*H*d ± SD	π ± SD	k	Haplotype labels
152 bp	5	167	10	0.836 ± 0.010	0.040 ± 0.002	6.10	i, ii, iii, iv, v, vi, vii, viii, ix, x
103 bp	6	210	8	0.775 ± 0.017	0.028 ± 0.001	2.89	(i + viii), ii, iii, iv, (v + vi), vii, ix, x

Using the longer alignment, 10 unique haplotypes were identified, compared to eight in the shorter alignment, reflecting reduced sequence resolution and haplotype amalgamation (Table 1; Fig. 4). With the longer alignment, each of three eastern PAs harboured six haplotypes, whereas Prey Lang contained three, and Chhaeb-Preah Roka two (Fig. 4). Population-specific haplotypes included iii (Keo Seima), vi and vii (Phnom Prich), viii (Srepok), and x (Prey Lang) (Fig. 4). Based on the shorter alignment, *H*d and π were highest in the three adjacent eastern populations (Keo Seima: 0.746, 0.029; Phnom Prich: 0.731, 0.033; Srepok: 0.810, 0.036), followed by the northern and central population (Chhaeb-Preah Roka: 0.571, 0.028; Prey Lang: 0.568, 0.007), and lowest in the western population (Cardamoms: 0.246, 0.002; Fig. 4).

*H*d in the Cardamoms was approximately three times lower than in eastern populations, and despite a larger sample size, almost half that of Prey Lang and Chhaeb-Preah Roka (Fig. 4). Both the alpha (a) and beta (b) clades co-occurred in the eastern populations and Chhaeb-Preah Roka, whereas haplotypes in Prey Lang and Cardamoms were restricted to the alpha clade (Fig. 4).

Patterns from the longer alignment were consistent, with three eastern populations exhibiting the highest diversity (0.746–0.830) and lower values in Chhaeb-Preah Roka (0.571) and Prey Lang (0.568). π values were broadly similar across populations (0.035–0.046), except for Prey Lang, which remained notably lower (0.005) (Fig. 4).

Due to sequence-length limitations, the Cardamoms population could not be aligned with the global sequence without further reducing haplotype resolution; the final dataset therefore remained identical to that analysed by Crouthers et al. (2026b), including the same three novel haplotypes identified in eastern Cambodia.

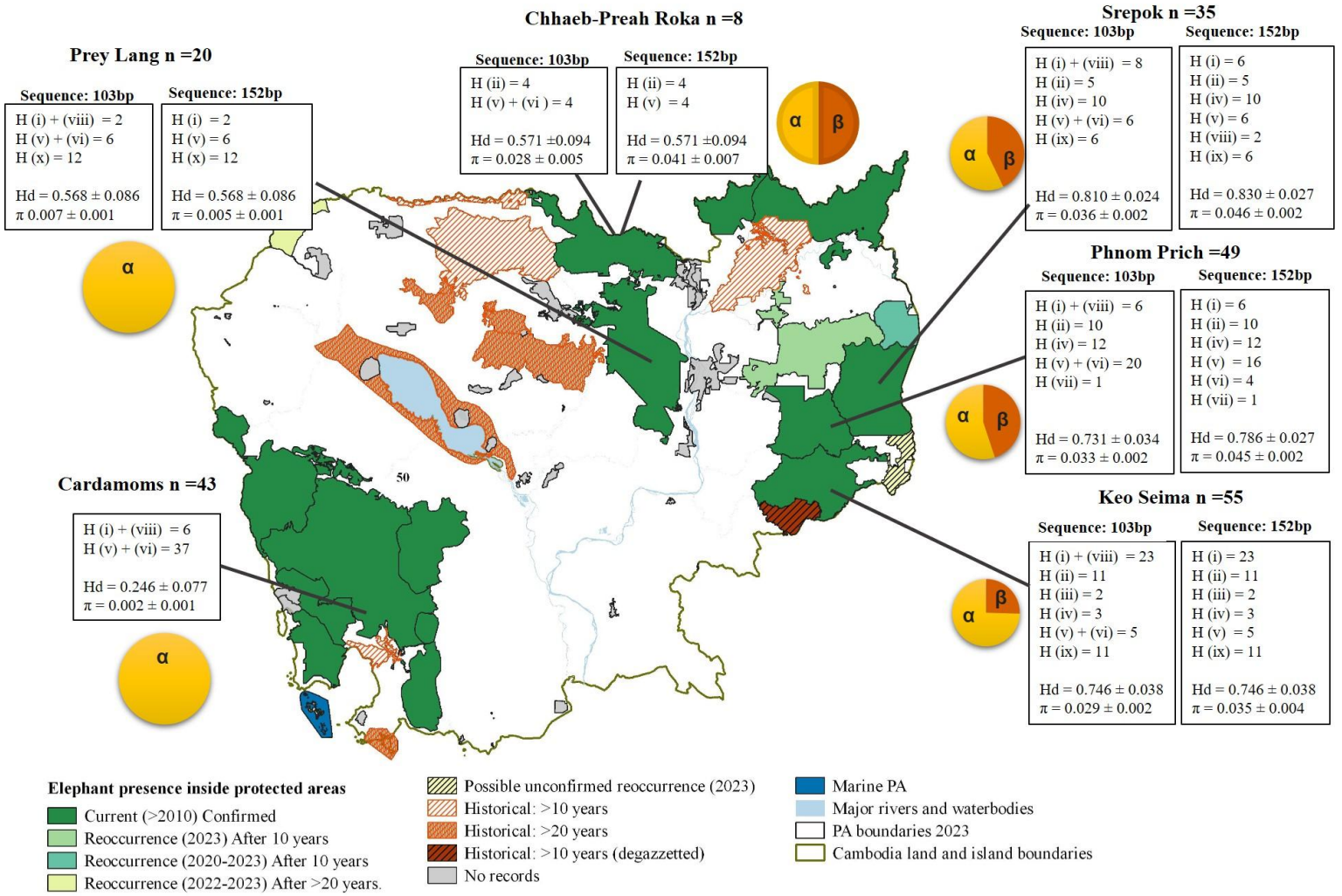


Fig. 4 Elephant presence and absence in Cambodia and number of wild elephant mtDNA sequences per protected area, number of haplotypes, haplotype diversity (Hd), nucleotide diversity (π) using the two different sequence lengths (103 bp and 152 bp). The circles represent the proportion of haplotypes belonging to each mtDNA clade, with α representing the alpha clade and β the beta clade

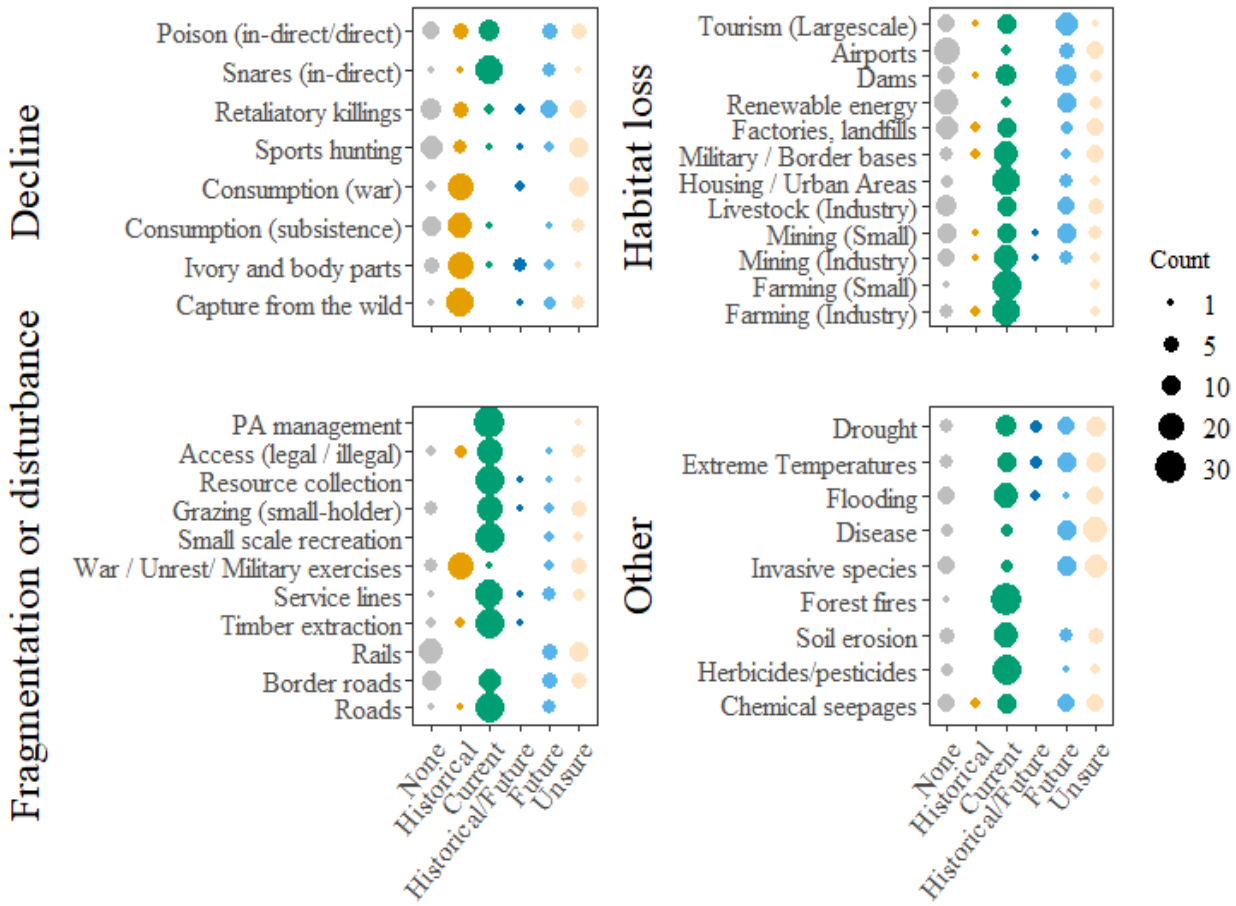
Elephant mortalities and threats

Questionnaire responses and consolidated workshop discussions identified 29 suspected non-natural wild elephant deaths between 2002 and 2023 (Online Resource 1 - Appendix 7). Reported causes were confirmed for 16 of these, including targeted hunting (n=9), snares (n=4), poison (n=1), retaliatory killings (n=1) and electrocution by powerline (n=1). Subsequent online searches and government meetings identified at least four additional suspected non-natural wild elephant deaths since 2023 (Online Resource 1 - Appendix 7).

Thirty-two respondents completed the threats section representing 17 of the 18 PAs supporting elephants, percentages are based on all respondents, including those who were unsure. Most direct threats to elephants (capture for captive purposes, hunting for products, consumption, or sports) were predominantly perceived to have ceased or no longer considered threats (Fig. 5). However, ≈20% considered hunting for products a future concern. Responses regarding retaliatory killings were more varied: ≈35% perceived this to not be a threat, while 25% considered it a future risk. Illegal hunting techniques targeting other wildlife were considered relevant to elephants both currently and in the future (Fig. 5), with 78% of respondents considering snares as a current threat, increasing to 91% when future threats were included.

The majority of economic development projects contributing to habitat loss were frequently viewed as current and/or future threats (Fig. 5). The top five current threats included industrial and smallholder agriculture, rural/urban expansion, military bases/settlements and industrial mining (Fig. 5). Dams, large tourism projects (e.g. resorts and associated infrastructure) and small-scale mining were commonly viewed as future threats (Fig. 5). Airports and renewable energy projects were not considered threats by 59% and 56% of respondents, respectively, although over a quarter perceived renewable energy as a future threat. Infrastructure or activities contributing to habitat fragmentation were predominantly viewed as current threats, except for railways (Fig. 5). International border roads were less frequently identified as a current concern. War/civil unrest/military exercise category was considered a historical threat by 63% of respondents. Human activities occurring inside PA boundaries were commonly viewed as current threats (Fig. 5).

Anthropogenic impacts such as forest fires, herbicides/pesticides, and agricultural-related soil erosion were perceived to be occurring inside PAs (Fig. 5). While the seepage of chemicals/pollutants was considered a lesser current threat, it was perceived to increase in the future (Fig. 5). Perceptions of invasive species and disease transmission were more uncertain, although both were identified as future threats (Fig. 5). Among climate-related factors, flooding and drought were perceived as current threats by 50% and 34% of respondents, respectively, while 25% and 38% perceived extreme temperature changes as current or future risks, respectively.



335

336 **Fig. 5** Threat assessment and perceived timescale for the four main threat categories; Decline, Habitat loss, Habitat

337 fragmentation or disturbance and Other. Circle size represents the number of responses

338 **Efficacy of current legislation/policy and PA management**

339 Thirty-two questionnaire responses were assessed on the perceived effectiveness of legislation/policy and law

340 enforcement/management inside PAs (Fig. 6). Half of the respondents rated laws/policies as highly effective (very or

341 extremely) in preventing targeted elephant hunting. This was followed by laws/ policies addressing small-scale habitat

342 loss/encroachment (40.6%), illegal wildlife hunting and logging (37.5% each), and retaliatory killings (34.4%). In contrast,

343 fewer respondents perceived laws/policies as highly effective for addressing large-scale habitat loss associated with

344 agricultural industries (18.8%) and commercial mining (12.5%).

345 Perceived efficacy of law enforcement and management efforts to reduce illegal crimes within PAs followed similar

346 trends (Fig. 6). Over one-third of respondents rated efforts as highly effective (very or extremely) in reducing habitat loss

(43.8%), targeted hunting (40.6%) and retaliatory killings (37.5%) (Fig. 6). In comparison, efforts to combat illegal wildlife hunting and logging were considered highly effective (very or extremely) by 31.3% and 25.0% of respondents, respectively.

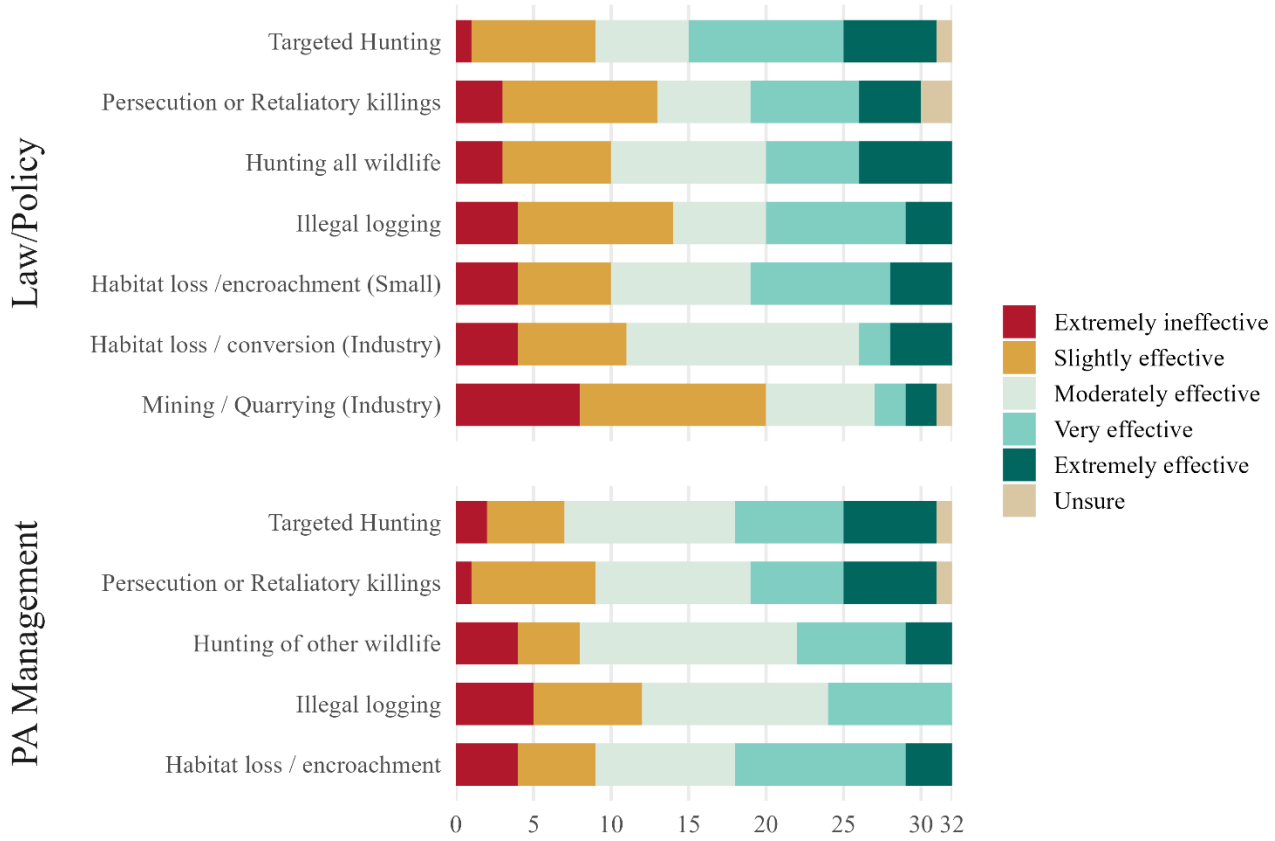


Fig. 6 Perceived efficacy of legislation and policies and law enforcement and management efforts in reducing threats inside protected area boundaries

Ranger data were available for all PAs with confirmed (n=18) and unconfirmed (n=1) elephant presence. Reported patrolling staff densities may slightly underestimate total capacity, as some PAs receive supplementary support from police officials and local residents, often through NGO funding. Given temporal and site-level variations, only MoE ranger numbers were used, with ranger densities ranging from 0.4–7.7 rangers/100 km² (mean = 2.1), with only two PAs exceeding 7 rangers/100 km²; all others supported <2.7 rangers/100 km² (Online Resource 1 - Appendix 8).

Negative human-elephant interactions: frequency, type and perceived impacts

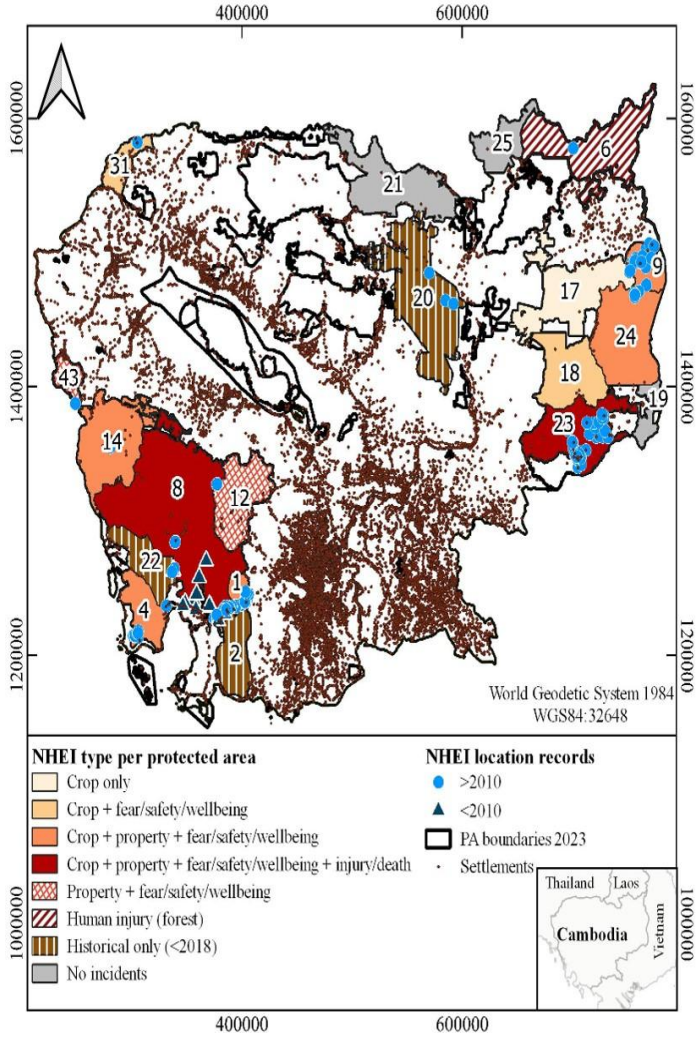
Post-hoc processing reduced the initial eight NHEI categories to six by combining fear/threat to safety and threat to wellbeing because of limited site-level data and excluding retaliatory killing because causes of mortality were often

unconfirmed. Kampong Seila (KS) district, outside the Cardamoms PA, was added after repeated incidents were reported during the 2023 workshop (Fig. 7).

Since 2010, at least one type of NHEI was reported in 16 PAs and KS district (Fig. 7), covering nine provinces (Online Resource 1 - Appendix 9). The longest-recorded NHEI activity (<2010 onwards) occurs in one eastern PA (Keo Seima; historical spatial data unavailable) and several southwestern locations. Since 2018, NHEIs have ceased in three PAs (Bokor, Prey Lang, and Tatai; Fig. 7), likely reflecting habitat loss/modification, anthropogenic disturbance, and/or changes in or cessation of agricultural practices. See Online Resource 1 - Appendix 10 for PA-level detail.

Between 2018 and 2023, ≥1 type of NHEI occurred in 13 PAs and KS district (Fig. 7), two of which (Lomphat and Phnom Prich) lacked spatial data but were retained based on expert knowledge (Online Resource 1 - Appendix 11). Recurring incidents were reported for 10 PAs and KS district, while Samlaut, Lomphat and Virachey, had only a few or isolated incidents. Fear for safety/wellbeing was not selected for Lomphat or Virachey, unlike all other sites, possibly reflecting the lower frequency/severity of incidents rather than an absence of risk (Fig. 7; Online Resource 1 - Appendix 11). Most incidents occurred within villages (8 PAs and KS district). Of these, three PAs reported the greatest number of affected villages: Keo Seima (12–13) and O'Yadav (6) in the east, and Cardamoms (6), while five PAs and KS district reported impacts in ≤2 villages (Fig. 7). By contrast, incidents in the remaining five PAs were limited to economic land concessions (Phnom Aural, Phnom Prich), military border areas (Banteay Chhmar and Samlaut), or forest (Virachey), with single isolated incidents in Samlaut and Virachey (Fig. 7; Online Resource 1 - Appendix 11). While Keo Seima and Cardamoms each reported four NHEI categories, including human fatalities, the NHEI intensity (spatial extent alongside the number of interaction types) was highest for Keo Seima and O'Yadav (Fig. 7).

Trends were generally perceived as stable (n=7) or increasing (n=5), with one site decreasing (Samlaut), and the likelihood of expansion into unaffected villages within the next five years varied from extremely likely (n=1) and somewhat likely (n=6) to neither likely nor unlikely (n=1) and somewhat unlikely (n=5) (Fig. 7).



ID	PA	Villages	Perceived Trend	Food sufficiency: Ability to provide food	Property damage: Daily living standards	Fear for personal safety: Daily lifestyle and wellbeing	Impact on economic status
Crop only							
17.	Lomphat	1	Stable	Minor/Low	n/a	n/a	n/a
Crop + fear/safety/wellbeing							
18.	Phnom Prich	Concession	Increasing	Minor/Low	n/a	Negligble	Minor/Low
31.	Banteay Chhmar	Border Post	Increasing	Negligible	n/a	Negligible	No data
Crop + property + fear/safety/wellbeing							
1.	Kirirom	2	Stable	Minor/ Low	Minor/Low	Moderate	Moderate
4.	Botum Sakor	2	Stable	Minor/Low	Moderate	Moderate	Moderate
9.	O'Yadav	6	Stable	Minor/Low	Moderate	Minor/Low	Minor/Low
14.	Phnom Samkos	2	Stable	Minor/Low	Negligible	Moderate	Minor/Low
24.	Srepok	1	Increasing	Minor/Low	Minor/Low	Minor/Low	Minor/Low
Outside PA	Kampong Seila	2	Increasing	Minor/Low	Minor/Low	Moderate	Minor/Low
Crop + property + fear/safety/wellbeing/ + Injury death							
8.	Cardamons	6	Stable	Minor/Low	n/a	Minor/Low	Minor/Low
23.	Keo Seima	12-13	Increasing	Moderate	Minor/Low	Moderate	Moderate
Property + fear/safety/wellbeing							
12.	Phnom Aural	Concession	Stable	n/a	Minor/Low	Minor/Low	n/a
43.	Samlaut	Border Post	Decreasing	n/a	n/a	n/a	n/a
Human injury (deep in forest)							
6.	Virachey	Forest only	n/a	-	-	-	-
Historical only (<2018)							
2.	Bokor	No data	-	-	-	-	-
20.	Prey Lang	2	-	-	-	-	-
22.	Tatai	1	-	-	-	-	-
None							
21.	Chhaeb-Preah Roka	-	-	-	-	-	-
25.	Siem Pang	-	-	-	-	-	-
19	Phnom Namlear	-	-	-	-	-	-

Fig. 7 Negative human elephant interactions (NHEIs) across Cambodia's protected areas, showing number of NHEI categories, historical (<2010) and current (≥2010) distribution, number of affected villages or concessions, perceived NHEI trends and overall perceived impacts to local residents including crop damage, property damage, fear for safety/ wellbeing and economic losses

Perceived impacts of NHEIs on affected villages varied by category. See Online Resource 2 (Q32–35) for category and impact-scale descriptions. Crop damage impacts on food sufficiency were generally ranked as minor/low, while impacts on house/property damage were more variable across PAs (Fig. 7). Fear for personal safety was ranked as moderate for nearly half the PAs, and overall economic impacts were mostly ranked as minor/low, followed by moderate (Fig. 7). The highest overall impacts were reported in Keo Seima and Botum Sakor, followed by Kirirom (Fig. 7).

During the study period (2002–2023), three human fatalities involving wild elephants were identified between 2008 and 2017. Post-validation workshop online searches and meetings identified two additional human fatalities, one in 2024 and one in 2025 (Online Resource 1 - Appendix 12). All five incidents reportedly occurred in forest environments, with two in the southwest and three in the east (all within KSWS), and involved fishing, collecting non-timber forest products, and snaring. In addition, mixed data and anecdote suggest at least seven additional human fatalities involving captive elephants since 2010: one in the southwest (2010) and six in the east (2010/11 to 2017/2018), reportedly involving five elephants (two of which killed two people each). Where details were available, incidents reportedly occurred in villages or forest, with most involving the death of owners or mahouts for a range of reasons (Online Resource 1 - Appendix 12).

Mitigation and deterrence methods

Ten respondents reported the current use of at least one mitigation/deterrence approach across seven PAs (Cardamoms, Botum Sakor, Keo Seima, Kirirom, O'Yadav, Phnom Samkos and Srepok). Multiple responses were received for Keo Seima, Phnom Samkos and Srepok (n=2 each). Of the 34 approaches, 29 were reported to be in current use, 27 of which received an efficacy rating (Fig. 8). Only one approach (reducing illegal land conversion) was rated extremely effective, whereas seven approaches were rated very effective, including explosive deterrents, permanent lights, guns, active elephant chasing, large living fences and electric fences (Fig. 8). Exclusionary and long-term barriers were the least implemented category, despite three being considered very or extremely effective (Fig. 8). Subsequent anecdote during the 2023 workshop suggested the effectiveness of most approaches was either temporary or insufficiently evaluated over time.

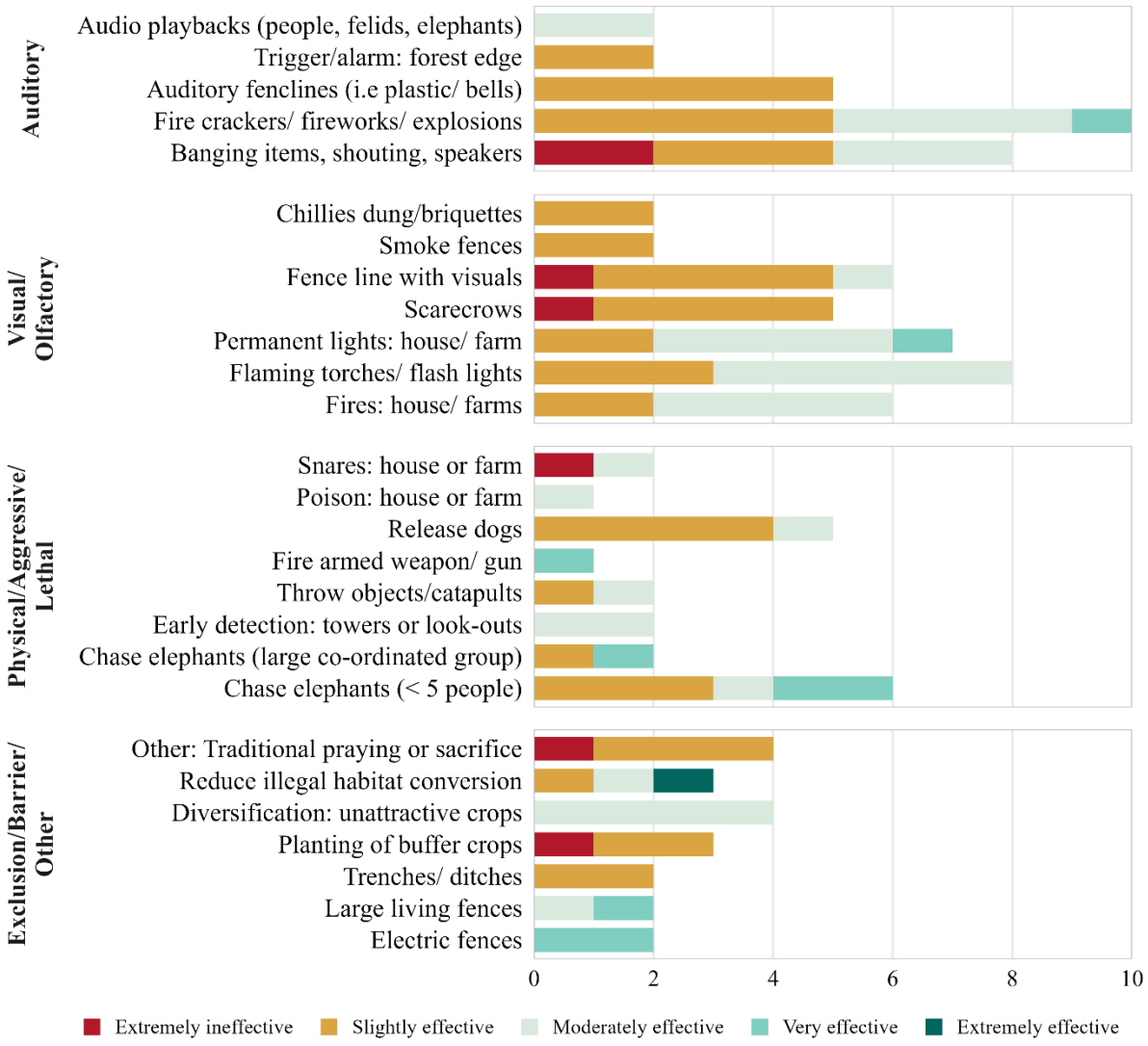


Fig. 8 Perceived efficacy of mitigation and deterrence approaches currently used inside protected areas

Discussion

Using a multi-stakeholder, integrative approach, this study provides the most comprehensive national-scale assessment of elephants' status in Cambodia to date. By combining spatial records, expert knowledge, questionnaires and workshops, we generated a national dataset identifying key population trends, distributional changes and conservation priorities. These findings provide an evidence base for prioritising conservation actions to maintain population persistence and support recovery, particularly among small and isolated populations.

Population size and regional significance

We confirmed elephant presence in PAs previously undocumented or from which elephants were presumed extirpated, estimated population size of all 18 extant populations (ranging from <10 to >100 individuals), and confirmed elephant absence in 9 currently recognised PAs. Our findings suggest that Cambodia supports more elephants than previously estimated.

Earlier national assessments suggested 400–600 individuals (Maltby and Bourchier 2011; GDANCP 2020), whereas our combined genetic CMR and expert-based assessments indicate 747–899 wild elephants (excluding one transient site). This difference likely reflects expanded survey coverage, increased use of genetic CMR, and improved understanding of population distribution rather than demographic growth. Three adjacent eastern PAs support populations exceeding 100 individuals each, and collectively contain over half of the national population, while two connected western PAs support a further 45–120 elephants. In contrast, all remaining populations were small (<45 individuals) and generally isolated, highlighting their greater vulnerability to local extirpation. Nevertheless, when compared with neighbouring countries (Thailand: 3126–3341; Laos: 500–600; and Vietnam: 104–132; Menon and Tiwari, 2019), Cambodia supports one of the largest remaining elephant populations in mainland Southeast Asia outside Thailand, underscoring its regional conservation importance.

Captive elephant population

The best available estimate as of December 2025 is 67 captive elephants. This represents a decline from 93 individuals in 2011 (Maltby and Bourchier 2011), largely reflecting limited recruitment and natural mortality in an ageing population. With the exception of a few juveniles, most captive elephants are now post-reproductive, while breeding remains rare and is still considered taboo in some Indigenous communities that own elephants. Several workshop participants, including government officials, expressed a desire for increased captive elephant numbers for cultural and conservation purposes. Given the small and ageing population and limited recruitment, any consideration of future population management will need to balance these cultural and conservation interests with appropriate safeguards for both captive and wild elephants. If the expansion of the captive population is pursued, it should rely exclusively on legally sourced captive elephants from outside Cambodia, including appropriately regulated imports, in accordance with national legislation, CITES requirements, and veterinary health and quarantine protocols.

Range shifts and connectivity

Both range contractions and expansions were evident across the country. However, apparent absences should be interpreted with caution, as the lack of recent records does not necessarily indicate true absence. Across Cambodia, and particularly in the southwest and northeast, gaps in records were attributed to limited survey resources and effort, poor accessibility, rugged terrain, small population sizes that are difficult to detect, and anthropogenic disturbance.

In the east, elephant reoccurrence was recorded in O'Yadav and Lomphat, with possible but unconfirmed movements into Phnom Namlear from Srepok. Although the drivers remain uncertain, habitat modification and anthropogenic pressures in Cambodia and Vietnam are likely influencing recent movement patterns, including transboundary movements. Cambodia-Vietnam transboundary movement corridors likely still include Keo Seima–Bù Gia Mập and Srepok–Yok Đôn, and more recently, O'Yadav to adjacent non-protected areas in Vietnam. However, movement patterns, key border-crossing points and changes in connectivity remain poorly understood. Moreover, population isolation appears to have emerged among some of Cambodia's largest populations, particularly between Keo Seima and Phnom Prich and within Srepok. This fragmentation is potentially driven by habitat modification/disturbance within and adjacent to concessions, together with settlement expansion, road development and other infrastructure. Maintaining and restoring habitat connectivity within and across this ~16,000 km² transboundary PA complex will be critical for long-term population viability and should be prioritised alongside efforts to reduce ongoing anthropogenic pressures within PAs.

Concerningly, the northeastern and central-northern populations appear increasingly isolated. Historical declines, local extirpations, and range contractions were primarily attributed to war, civil unrest, targeted hunting, live capture and habitat modification. In the northeast, only small, fragmented groups appear to persist in Virachey and possibly Siem Pang, although limited survey coverage precludes firm conclusions. In the central–northern region, elephants are now absent from five formerly occupied PAs, and consistent with Sinovas et al. (2025), the remaining Prey Lang and Chhaeb-Preah Roka populations appear to no longer function as a connected metapopulation due to extensive habitat fragmentation.

Only one northwestern site (Banteay Chhmar) supports elephants. Despite no previous records from the area, information suggests that these individuals may have dispersed from Huai Thap Lan–Huai Samran Wildlife Sanctuary (A. Jitvijak, WWF pers. comms., 2023). If confirmed, this would represent an important example of transboundary range expansion. However, associated NHEIs at military border posts also highlight the need for coordinated transboundary management and conflict-mitigation measures.

The ~21,500 km² western PA complex exhibits considerable variation in population size and connectivity. While the Cardamoms–Tatai population appears to function as a single relatively large population, Bokor and Samlaut are considered isolated from other Cambodian populations. Samlaut may still form part of a transboundary population shared with Thailand, as previously proposed by Maltby and Bourchier (2011), although movement data near the international border remain lacking. Ongoing road construction and associated infrastructure along the border may further constrain connectivity, highlighting the need to identify and secure functional crossing points. Recent fragmentation between Bokor and Kirirom highlights the growing influence of linear infrastructure. Increased traffic along National Road 4, the newly constructed Phnom Penh–Sihanoukville Expressway, and expanding roadside settlements now act as effective barriers to dispersal, despite continued occurrence near these transport corridors. Restoring connectivity between these populations may therefore be critical for their long-term persistence.

Overall, substantial knowledge gaps remain, particularly across western Cambodia and other remote, resource-limited PAs. Rugged terrain, restricted access and limited survey effort have contributed to persistent uncertainty regarding elephant presence, distribution and connectivity. Although research effort has increased in recent years, systematic co-ordinated monitoring remains limited. Consolidating existing datasets and expanding targeted surveys should be a national priority for landscape-scale conservation planning. Such efforts would improve understanding of elephant distribution and connectivity while helping identify movement bottlenecks and mitigation opportunities in landscapes increasingly fragmented by infrastructure. International best-practice guidance (Ament et al. 2021; Dodd et al. 2024) recommends assessing historical movement routes, traffic patterns, and the broader landscape context before implementing mitigation measures, which may include non-structural (e.g. road signs, flashing lights, traffic calming measures) and structural (e.g. underpasses, overpasses, bridges, fly-overs). Such assessments should be prioritised in both the western and eastern elephant landscapes.

Genetic diversity and regional significance

Genetic diversity varied across Cambodia's elephant populations, being highest in the eastern protected area complex (Keo Seima, Phnom Prich and Srepok), moderate in the central–northern region, and lowest in the sampled western population. Both mitochondrial haplotype clades were detected across eastern and northern populations, indicating that eastern Cambodia represents the country's primary genetic stronghold, consistent with previous findings by Crouthers et al. (2026b), who reported comparatively high diversity relative to other regional populations and three novel haplotypes. This underscores the regional importance of eastern populations for elephant conservation, although recent anthropogenic

fragmentation appears to be reducing population connectivity. Given long generation times of elephants, the genetic impacts may only become fully evident in the future (Crouthers et al. 2026b), thus continued isolation could erode diversity and resilience over time. In contrast, the western population showed the lowest mitochondrial diversity, with only two haplotypes detected, both belonging to the alpha clade shared with other regions. This may reflect historical bottlenecks, isolation, or limited female dispersal. Reduced diversity increases population vulnerability and may limit adaptive potential, particularly if fragmentation continues. However, the short sequence length constrains interpretations and global comparisons, and further sampling in western Cambodia is needed to clarify these patterns. Overall, these results highlight the need to safeguard high genetic diversity in eastern populations while prioritising connectivity restoration and genetic monitoring of western and other isolated populations to support long-term viability.

Anthropogenic threats

Across parts of southeast Asia, demand for elephant skin and associated trade represents a major conservation concern (Elephant Family 2018; Sampson et al. 2018). In Myanmar, ≈55 elephant carcasses were recorded over 2.5 years, predominantly killed for meat and skin rather than ivory (Sampson et al. 2018). This threat was not reported in Cambodia, where targeted hunting has largely ceased, although some respondents identified ivory or wildlife product trade as a potential future risk.

While the problem of illegal live capture and trade persist in parts of Asia (Duckworth and Hedges 1998; Baskaran et al. 2011; Riddle and Stremme 2011; Prakash et al. 2020b), wild elephant capture has been illegal in Cambodia since the mid-1990s (Maltby and Bourchier 2011) and was generally considered to have ceased. Given the small size and isolation of many remaining wild populations, removal of wild elephants could have significant demographic and ecological consequences and would contravene existing legislation. The use of legally sourced captive elephants from outside Cambodia, as outlined above, would therefore avoid the need to remove animals from wild populations while reducing the risk of illegal capture and/or associated cross-border trade.

The principal contemporary threat contributing to population declines is indiscriminate snaring, followed by poisoning, both used to target other wildlife species. Snaring has become a pervasive conservation challenge across Southeast Asia, with thousands of snares removed annually from PAs (Gray et al. 2021), including Cambodian elephant sites. Although elephants are not the intended target, snare-related injuries and mortalities, particularly of juveniles, have been documented in Cambodia (Un et al. 2018; Gray et al. 2021), a pattern also confirmed in this study. Consequently, elephants are likely to remain at risk wherever snaring persists.

Habitat loss and fragmentation within PAs were also widely perceived as ongoing threats. Agricultural expansion, plantation development, and logging were identified as the primary drivers of recent forest loss in Cambodia's elephant landscapes (Luo et al. 2022). Continued forest conversion risks further isolating already small populations and increases the likelihood of local extirpation. Strengthening legislation, management strategies and law enforcement is therefore essential.

Government ranger densities in most elephant PAs remain far below the thresholds recommended by Appleton et al. (2022), limiting effective protection. Without increased staffing and resources, conservation may remain below the level required to support long-term elephant metapopulation persistence. In the interim, enhanced cross-sector and transboundary collaboration will be necessary to maintain forest connectivity and reduce anthropogenic pressures within and across elephant landscapes.

Negative human-elephant interactions

Our findings indicate that NHEIs are geographically widespread with substantial spatial variation in their intensity and persistence. A previous study identified severe but largely localised NHEIs in four provinces: three in the southwest (Kampong Speu, Koh Kong and Preah Sihanouk) and one in the east (Mondulkiri) (Webber et al. 2011). Our study expands this distribution, documenting singular or repeated incidents across five additional provinces: Pursat, Battambang, Stung Treng, Oddar Meanchey, and Ratanakiri.

Since 2010, NHEIs have been recorded in 16 PAs and Kampong Seila district, with the majority of these sites experiencing varying levels of NHEI since 2018. Intensity (distribution and frequency) was highest in Mondulkiri and Ratanakiri provinces in the east, while recurring yet more localised incidents occurred in parts of the southwest, particularly Kampong Speu, Preah Sihanouk and Koh Kong provinces. Although Webber et al. (2011) reported reductions in NHEI following mitigation efforts, our findings indicate ongoing incidents at several of the same locations. This persistence, alongside the occurrence of NHEIs in additional areas, suggests that existing mitigation has not consistently prevented recurrence. Furthermore, while some mitigation measures were considered partially effective, most were considered insufficient to prevent long-term recurrence, likely because interventions were predominantly reactive and implemented on an ad hoc basis.

This assessment provides a preliminary national overview of NHEI occurrence, mitigation approaches, and perceived efficacy. However, it does not capture the underlying social or cultural dimension or the perspectives of affected residents. Zimmermann et al. (2020) suggested human-wildlife conflict often occurs at three levels, some of which can be frequently overlooked and may result in reactive and/or inadequate solutions. This is likely the case for many residential

553 settlements and private landowners experiencing NHEIs in Cambodia. Future concentrated efforts should therefore focus on
554 the identified hotspots from our research to better understand local perceptions, underlying social drivers, and impacts. Such
555 evidence would support future multi-stakeholder engagements in developing suitable co-designed site-based interventions
556 and strategies that support the wellbeing of both people and elephants in shared landscapes.

557 **Conclusions and conservation implications**

558 This study highlights Cambodia's regional conservation significance for supporting varying-sized elephant
559 populations with differing levels of genetic diversity, with the largest and most genetically diverse populations occurring in
560 the east of the country. Although elephants persist in 18 PAs, many populations have undergone range contractions and
561 remain vulnerable due to small size, isolation and fragmentation. Historical drivers, including war, civil unrest, targeted
562 hunting, live capture and habitat modification have contributed to widespread declines, as well as elephant absence in nine
563 currently recognised PAs. Contemporary habitat modification and fragmentation continue to threaten long-term persistence,
564 particularly populations numbering fewer than 45 individuals.

565 Conservation priorities include habitat preservation, restoring functional landscape connectivity, and strengthening
566 legislation, management and law enforcement. These actions are especially important for small, fragmented populations. The
567 absence of official management zones in many PAs poses a significant challenge in balancing conservation with socio-
568 economic wellbeing and development. Meanwhile, since 2018 ongoing NHEIs of various scales and types were reported in
569 11 sites, irrespective of population sizes and landscapes. As interactions appear to be increasing in frequency and intensity,
570 the management of shared spaces becomes progressively more complex. Stakeholders must prioritise the development and
571 adoption of strategies to address and mitigate the impacts of existing NHEIs while proactively preventing negative
572 interactions before they arise.

573 Overall, this study provides valuable insights into data-deficient elephant populations across diverse socio-
574 ecological landscapes, emphasising the need for interdisciplinary conservation approaches and strategies. The integration of
575 spatial datasets, questionnaires alongside multi-stakeholder workshops facilitated comprehensive data collection, while
576 fostering open dialogue among decision-makers and stakeholders. These findings can also inform future policy-making and
577 decision processes at both site and national levels. Moreover, the techniques and approaches used here are reproducible and
578 transferable to other data-deficient elephant range sites and potentially other cryptic, elusive and/or wide-ranging species.
579 Results from this multi-faceted approach can facilitate the identification of populations requiring immediate conservation
580 attention, enabling the development of data-informed management actions to safeguard population survival.

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Statements and Declarations

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Data Availability

Summary data are provided in the article and Online Resources. Mitochondrial DNA haplotype sequences have been deposited in NCBI GenBank: four haplotypes from the Prey Lang Extended Landscape (accession numbers PP066116–PP066119; Sinovas et al. 2025) and nine haplotypes from Srepok and Phnom Prich Wildlife Sanctuaries (PP997988–PP997996; Crouthers et al. 2026b); unpublished Cardamom sequences may be available from the providing organisations, Fauna & Flora and RZSS. Other spatial and mtDNA data were compiled from published studies, government and NGOs, some under data-sharing agreements; precise elephant locations are withheld owing to species sensitivity. These data may be available from the corresponding author on reasonable request, subject to data-sharing agreements and permission from the data owners, or otherwise directly from the co-authors and/or organisational representatives named in the Acknowledgements. Individual questionnaire responses are confidential under the ethics approval.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Compliance with Ethical Standards

The questionnaire survey, project description and consent form were reviewed and approved by the Te Herenga Waka–Victoria University of Wellington Human Ethics Committee (Ref. 27101). Informed consent was obtained from all individual participants prior to taking part. Participation was voluntary, and respondents could remain anonymous or choose to provide contact details, which were kept confidential to the lead researcher and transcriber.

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