Legacy effects of locally extinct flagship species on protected areas

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Protected areas (PAs) are often established to conserve flagship megafauna so as to mobilize political support and secure sustained conservation investment, with the expectation that flagship-centered governance will also protect habitat. Despite such efforts, flagship species can experience extirpation, raising a fundamental question: do conservation systems endure beyond the species that inspired protection? Using a causal-inference framework combining propensity-score matching and the synthetic-control method, we compared observed forest loss to counterfactual expectations before and after extirpation of the Javan rhinoceros (*Rhinoceros sondaicus*) from Vietnam's Cat Tien National Park and tiger (*Panthera tigris*) from Laos's Nam Et–Phou Louey National Park. Our results show that forest loss trajectories did not change after flagship species extirpation, but pre-extirpation effectiveness differed. Cat Tien functioned better than expected, while Nam Et–Phou Louey fell short of expectations, and these trajectories persisted. Ultimately, PA effectiveness was shaped not by flagship species extirpation but rather by the underlying management capacity.

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Flagship species have long played a prominent role in conservation due to their charismatic qualities. They help raise public awareness for species conservation, attract funding, and mobilize political and public support for the creation of protected areas (PAs) (Johnson 2012a; Brook *et al.* 2014; Li and Pimm 2016; Lamba *et al.* 2023). While the flagship concept has been widely used in conservation campaigns, its influence often extends beyond the species themselves (Li and Pimm 2016). Investment in flagship-focused programs can shape institutional capacity, infrastructure, law enforcement, and local community engagement in PAs (Johnson 2012b; Brook *et al.* 2014). For example, the national park that supported the last known population of Javan rhinoceros (*Rhinoceros sondaicus*) in Vietnam received better protection, more rigorous monitoring, and additional multi-million-dollar funding as compared to most other PAs in the region (Brook *et al.* 2014). In principle, such efforts are expected to extend beyond population-level benefits by strengthening habitat protection and reducing forest loss pressures within PAs (Lamba *et al.* 2023).

Flagship-focused investments like ranger training, biodiversity monitoring, fundraising, and institutional structuring often persist even after a flagship species has been biologically extirpated. These lasting impacts, termed "conservation legacies", occur in the interval between biological and societal extinction, when the species continues to hold societal salience despite no longer being present (Jarić *et al.* 2022). Although the loss of flagship species is often viewed as a conservation failure, it remains unclear whether conservation legacies would continue to maintain positive environmental outcomes after the species themselves have been extirpated (Rasphone *et al.* 2019; Roberts *et al.* 2025).

Here, we used a causal-inference framework to test whether forest loss in PAs differed from counterfactual expectations before and after the extirpation of two charismatic flagship species: the Javan rhinoceros in Cat Tien National Park in Vietnam and the tiger (*Panthera tigris*) in Nam Et–Phou Louey National Park in Laos. Both national parks were established by merging multiple existing PAs, and conservation action plans were devised to both protect and increase the populations of these flagship species (Johnson 2012a; Brook *et al.* 2014; Johnson *et al.* 2016; Rasphone *et al.* 2019; Long *et al.* 2025). Within this framework, we examined whether flagship-associated investments influenced conservation trajectories along two independent dimensions: pre-extirpation effectiveness in reducing forest loss and post-extirpation stability of forest protection.

Methods

Study area and flagship species

Our study focused on two PAs: Cat Tien National Park (hereafter, Cat Tien NP) in Vietnam (11.4239°N, 107.4320°E; 73,878 ha) and Nam Et–Phou Louey National Park (hereafter,

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Nam Et–Phou Louey NP) in Laos (20.517794°N, 103.592093°E; 507,000 ha).

Cat Tien NP was established in 1998 as a merger between Cat Loc Rhinoceros Sanctuary (established in 1992; 30,635 ha), Tay Cat Tien Nature Reserve (established in 1978; 5143 ha), and Nam Cat Tien Nature Reserve (established in 1978; 38,100 ha), specifically to protect the world's rarest megaherbivore, the Javan rhinoceros (Hughes *et al.* 2004; Brook *et al.* 2014). The park's management and branding explicitly positioned the Javan rhinoceros as its flagship species, featuring it on the park's logo and embedding it throughout successive management plans and international partnerships (Brook *et al.* 2014). Rhinoceros-focused investments (US$19 million cumulatively between 1998 and 2007) in dedicated patrol and monitoring units, specialized ranger training, and village resettlement programs were unparalleled among Vietnam's PAs (Hughes *et al.* 2004; Long *et al.* 2025). Other PAs in Vietnam received an estimated US$894 per square kilometer in annual funding (Brook *et al.* 2014). In Vietnam, no other PA (or species) received comparable protection or funding as compared to Cat Tien NP (or to the Javan rhinoceros), and few parks in the region have so tightly aligned their institutional identity to a single species (Hughes *et al.* 2004; Brook *et al.* 2014).

Similarly, Nam Et–Phou Louey NP was established in 2001 as a merger between two contiguous PAs in Laos, Nam Et and Phou Louey, which were both originally established under Prime Minister's Decree 164 in 1993 (Johnson 2012a; UNEP-WCMC and IUCN 2025). The park was home to the most important tiger population in Laos (Johnson 2012a,b; Johnson *et al.* 2016), until the last known individual disappeared in 2014 (Rasphone *et al.* 2019). Governance of Nam Et–Phou Louey NP relied on a co-management framework involving the Laotian Ministry of Agriculture and Forestry, local communities, and the non-governmental organization (NGO) Wildlife Conservation Society, with funding from government and international donors, including the NGO Panthera and the US Fish and Wildlife Service's Rhino and Tiger Conservation Fund; the park emphasized the tiger as its flagship species, which was featured on the park's logo (Johnson 2012b). The park received more than US$600,000 cumulatively between 2002 and 2016 for tiger conservation (Guénard *et al.* 2025), considerably more than the ~US$0–5000 in annual funding received by other PAs in the country (Parr *et al.* 2024). The park's management plan explicitly prioritized tiger recovery, community outreach, and law enforcement patrols, which in turn garnered sustained financial inputs and institutional partnerships (Johnson *et al.* 2016; Rasphone *et al.* 2019).

Spatial datasets

We used the February 2024 version of the World Database on Protected Areas (WDPA) (UNEP-WCMC and IUCN 2025) to determine PAs established in Vietnam and Laos before 2000. Only PAs established before 2000 were selected because forest loss rates within PAs were calculated from 2000 onward.

We used data from the Global Forest Cover Change dataset to measure forest loss within PAs (Hansen *et al.* 2013) and from the Global Drivers of Forest Loss dataset to determine forest loss drivers within PAs (Sims *et al.* 2024). Google Earth Engine (GEE) was used to extract a suite of environmental, biophysical, and socioeconomic variables for PAs in Vietnam and Laos, aiming to capture the structural drivers of forest loss for counterfactual analysis via propensity-score matching and synthetic control (Gorelick *et al.* 2017). See Appendix S1: Panel S1 for details.

Control areas

Treated and control PAs must be relatively similar in size to avoid systematic bias (Lamba *et al.* 2023; Sreekar *et al.* 2024). Therefore, we omitted all PAs that were smaller than 100 km^2 from the control pool. The control PAs in Vietnam (n = 20) and Laos (n = 14) lacked Javan rhinoceros and tiger populations, respectively, and generally lacked species-specific flagship initiatives.

Pre-extirpation causal analysis using propensity-score matching

We used pixel-level matching to estimate pre-extirpation effects of flagship conservation. Specifically, we compared annual rates of forest loss in PAs with flagship species (treated units) before species extirpation to annual rates of forest loss in PAs without flagship initiatives (control units). Comparisons were restricted to PAs within the same country and over the same time period. Matching was conducted using propensity scores at the 1-km^2 pixel level to balance key socioecological drivers of forest loss (Appendix S1: Panel S1). We assessed covariate balance using standardized mean difference (SMD), and a threshold of 0.25 was set between treated and control units (Teo *et al.* 2025). We estimated the average treatment effect on the treated (ATT) as the difference in forest loss between treated pixels and their matched controls, using weighted regression models fitted to matched samples. See Appendix S1: Panel S1 for details and a sensitivity analysis.

Post-extirpation causal analysis using the synthetic-control method

We used the synthetic-control method to estimate the effect of flagship species extirpation on forest loss. The method constructs a "synthetic" counterfactual from a weighted combination of similar control PAs (PAs without flagship initiatives) that best replicate the treated PA's pre-extirpation forest loss trajectory (Abadie *et al.* 2010). This synthetic unit represents the forest loss trajectory in the absence of flagship species extirpation, allowing quantification of additional forest loss associated with the extirpation event. We used a placebo

test that falsely assigns treated status to control units and creates a synthetic control for each to determine whether the observed differences were not due to random chance. If the mean squared prediction error (MSPE) ratio for the treated unit was higher or lower than the 95% quantile range of the placebo units, then the extirpation event was considered to have had a significant effect on forest loss (Lamba *et al.* 2023; Sreekar *et al.* 2024). See Appendix S1: Panel S1 for details and a sensitivity analysis.

Results

Extirpation of Javan rhinoceros from Cat Tien NP, Vietnam

In 2000, Cat Tien NP protected 66,400 ha of forest. Between 2001 and 2023, 1020 ha (1.5%) of forest cover was lost within the park, of which 973 ha (95.4%) can be directly attributed to permanent agriculture, 1 ha (<0.1%) to shifting cultivation, 26 ha (2.5%) to logging, 20 ha (2%) to other natural disturbances, and 0 ha to wildfire, settlements, and hard commodities (that is, the exploration for, as well as the capture/extraction and processing of, geological resources, including mining- and energy-related infrastructure such as power plants and lines, oil drilling and refineries, and wind and solar farms) (Appendix S1: Figure S1).

Cat Tien NP exhibited significantly lower annual rates of forest loss before Javan rhinoceros extirpation, when comparing treated pixels to their matched counterparts elsewhere in Vietnam (estimate ± standard error = −0.192 ± 0.042, $P < 0.001$; Figure 1), which translated into ~1275 ha of forest that would have been otherwise lost between 2000 and 2010.

Observed and synthetic control followed a similar forest loss trajectory after Javan rhinoceros extirpation in 2010 (Figure 2). Results from our placebo test showed that the MSPE ratio for Cat Tien NP was 18.58, which was within the 95% quantile range of the placebo units (2.5% to 97.5% range = 2.99 to 399.4), suggesting that there was no significant increase in forest loss after Javan rhinoceros extirpation.

Extirpation of tiger from Nam Et–Phou Louey NP, Laos

In 2000, Nam Et–Phou Louey NP protected 454,300 ha of forest. Between 2001 and 2023, 39,913 ha (8.8%) of forest cover was lost within the park, of which 37,844 ha (94.8%) can be directly attributed to shifting cultivation, 1878 ha (4.7%) to permanent agriculture, 133 ha (0.3%) to logging, 38 ha (<0.1%) to other natural disturbances, 18 ha (<0.1%) to settlements, 2 ha (<0.1%) to hard commodities, and 0 ha to wildfire (Appendix S1: Figure S1).

Nam Et–Phou Louey NP exhibited significantly higher annual rates of forest loss before tiger extirpation, when comparing treated pixels to their matched counterparts elsewhere in Laos (estimate ± standard error = 0.110 ± 0.018, $P < 0.001$; Figure 1), which led to an additional ~6869 ha of forest lost between 2000 and 2014.

Observed and synthetic control followed a similar forest loss trajectory after tiger extirpation in 2014 (Figure 2). Results from our placebo test showed that the MSPE ratio for Nam Et–Phou Louey NP was 8.25, which was within the 95% quantile range of the placebo units (2.5% to 97.5% range = 2.62 to 39.08), suggesting that there was no significant increase in forest loss after tiger extirpation.

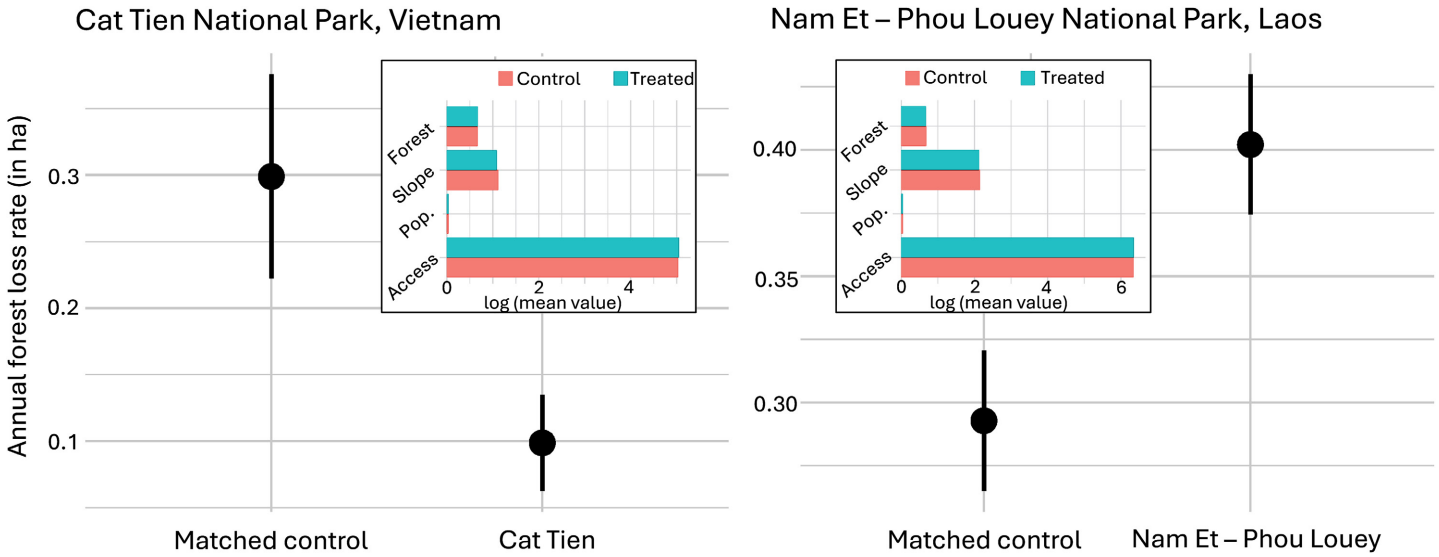


Figure 1. Comparison of forest loss between 1-km^2 pixels in treated flagship protected areas (PAs) and matched control PAs. Circles show weighted mean forest loss and error bars indicate 95% confidence intervals. Forest loss per pixel was converted to hectares to enhance interpretability. Inset bar charts show covariate balance between treated flagship PA pixels (teal) and matched control pixels (salmon). The covariates "forest", "slope", "pop", and "access" refer to baseline forest cover, topographic slope angle, human population density, and travel time from cities for the year 2000, respectively (see Appendix S1: Panel S1 for details).

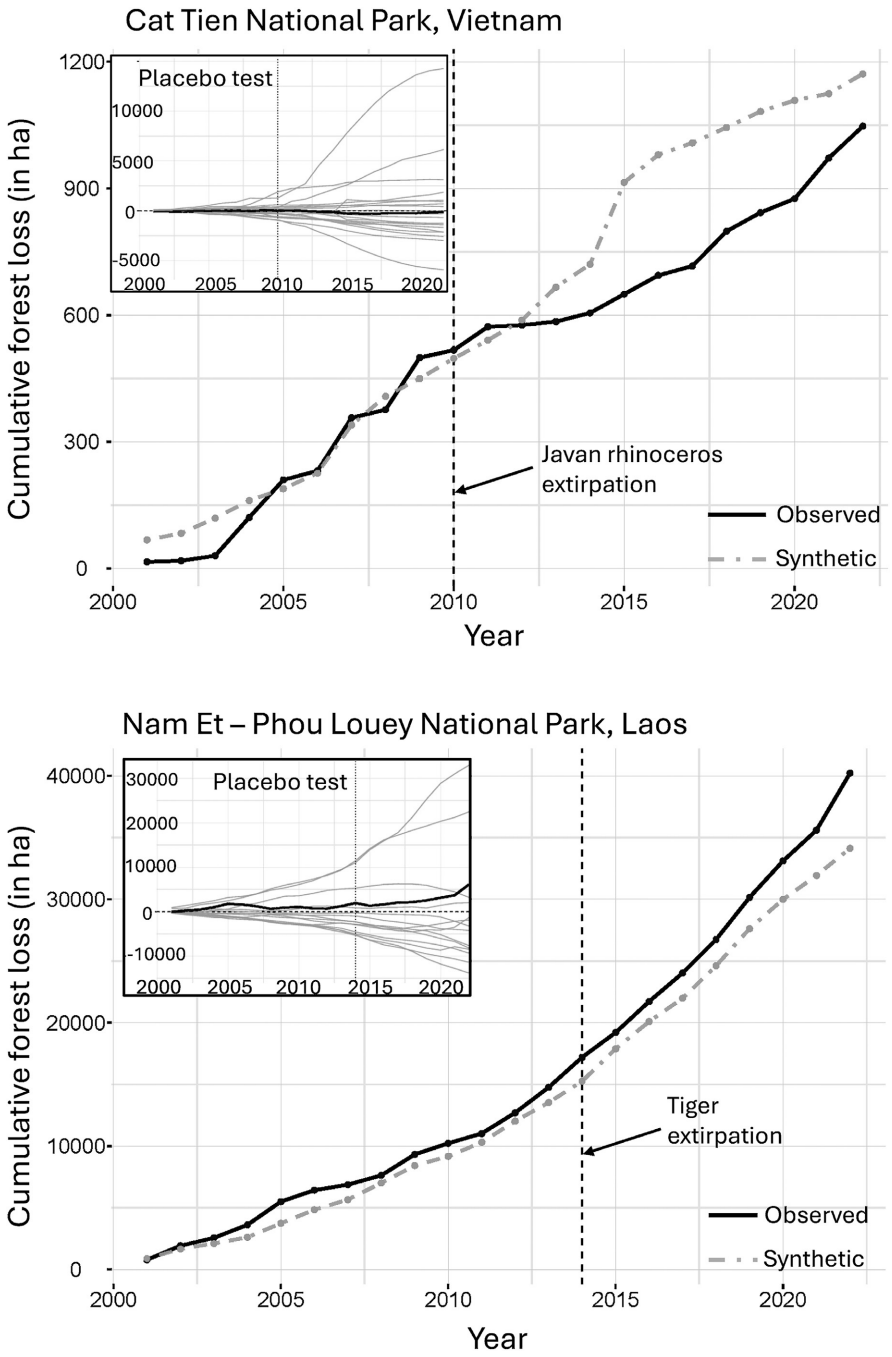


Figure 2. Cumulative forest loss (in hectares) within focal protected areas did not significantly change after extirpation of flagship species. Inset plots show placebo tests: the observed differences in cumulative forest loss (*y* axis) between the focal unit and its synthetic control (black lines) closely overlap with the differences between the placebo units and their synthetic controls (gray lines). This finding indicates that forest loss rates were not significantly affected by extirpation of Javan rhinoceros in Cat Tien National Park (top) or tiger in Nam Et–Phou Louey National Park (bottom).

Discussion

Extirpation of flagship species did not alter forest-loss trajectories in either national park. Where flagship-centered governance had been effective, forest protection remained strong. However, where anthropogenic pressures had overwhelmed management capacity, forest protection remained constrained. Ultimately, PA effectiveness was influenced by management capacity, not by local extinction of flagship species.

Pre-extirpation rates of forest loss differed between the two case studies, highlighting the context-dependent nature of flagship effectiveness. Counterfactual analysis revealed that Cat Tien NP experienced lower-than-expected forest loss before Javan rhinoceros extirpation, consistent with a causal role of flagship-associated conservation investments in strengthening protection and reducing forest loss (Lamba *et al.* 2023). In contrast, Nam Et–Phou Louey NP experienced higher-than-expected forest loss before tiger extirpation, suggesting that flagship-associated investments were insufficient to compensate strong structural pressures such as shifting cultivation, which was legally permitted inside the park (Rasphone *et al.* 2019; Parr *et al.* 2024). Therefore, the management priorities of governments and local communities play a dominant role in influencing conservation outcomes even when flagship species are present.

Our analysis is limited to 13 years after Javan rhinoceros extirpation from Cat Tien NP in Vietnam and 9 years after tiger extirpation from Nam Et–Phou Louey NP in Laos. Although these periods may appear short in the context of long-term conservation, they fall within a critical interval during which the effects of earlier conservation investments would still be expected to persist (Jarić *et al.* 2022). The planned reintroduction of tigers within Laos by 2035 (WWF 2022) further indicates that political commitment remains in place, suggesting that conservation systems built around flagship species have not been abandoned.

However, after flagship species extirpation, an absence of increased forest loss does not imply an absence of long-term consequences. For instance, forest loss in Nam Et–Phou Louey NP exhibited an upward though statistically insignificant trend, which could become concerning over time. Declining attention and reduced international funding may gradually erode conservation capacity. Therefore, continued monitoring over coming decades will be essential to determine whether these conservation legacies endure or eventually weaken.

We acknowledge that forest loss captures only one dimension of conservation impact. In Nam Et–Phou Louey NP,

investments in tiger protection supported prey recovery, deterred hunting, and benefited other threatened species (Johnson 2012b; Johnson *et al.* 2016; Rasphone *et al.* 2019), suggesting that conservation legacies may extend beyond landscape change to broader biodiversity outcomes. However, while data limitations prevented us from directly evaluating these biological responses, they highlight the importance of integrating landscape and biodiversity indicators, where possible, to fully assess the long-term consequences of flagship-driven conservation.

Conclusions

The loss of flagship species does not necessarily lead to deterioration of the PAs established for their conservation, at least over the timescales examined. However, the effectiveness of flagship-driven PA management is context dependent, and post-extirpation outcomes reflect the robustness of pre-extirpation governance capacity. Flagship species can attract substantial funding and political support, strengthening management and enforcement (Li and Pimm 2016; Lamba *et al.* 2023; Guénard *et al.* 2025), yet such investments are not always sufficient to overcome persistent anthropogenic and socioeconomic pressures. Where flagship initiatives successfully build durable institutions and facilitate sustained financing, PAs can continue moderating environmental pressures even after the species that inspired protection has been extirpated.

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Data Availability Statement

Data and code (Sreekar *et al.* 2026) are available on Zenodo at 10.5281/zenodo.19025209.

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