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1 **Effectiveness of 20 years of conservation investments in** 2 **protecting orangutans**

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110 assessment; Indonesia; Malaysia; orangutan; Pongo; tropical forest

111 **Summary**

112 Conservation strategies are rarely systematically evaluated, which reduces transparency, hinders the cost-
113 effective deployment of resources, and hides what works best in different contexts ¹. Using data on the
114 iconic and critically endangered orangutan (*Pongo* spp.), we developed a novel spatiotemporal framework
115 for evaluating conservation investments. We show that around USD 1 billion was invested between 2000
116 and 2019 into orangutan conservation by governments, non-governmental organizations, companies and
117 communities. Broken down by allocation to different conservation strategies, we find that habitat
118 protection, patrolling and public outreach had the greatest return-on-investment for maintaining orangutan
119 populations. Given variability in threats, land-use opportunity costs, and baseline remunerations in
120 different regions, there were differential benefits-per-dollar invested across conservation activities and
121 regions. We show that, while challenging from a data and analysis perspective, it is possible to fully
122 understand the relationships between conservation investments and outcomes, and the external factors that
123 influence these outcomes. Such analyses can provide improved guidance towards more effective
124 biodiversity conservation. Insights into the spatiotemporal interplays between the costs and benefits driving
125 effectiveness can inform decisions about the most suitable orangutan conservation strategies for halting
126 population declines. While our study focuses on the three extant orangutan species of Sumatra and Borneo,
127 our findings have broad application for evidence-based conservation science and practice worldwide ¹.

128

129 **Introduction**

130 The three orangutan species, *Pongo pygmaeus* in Indonesian and Malaysian Borneo, and *P. abelii* and *P.*
131 *tapanuliensis* in Sumatra, Indonesia, are in rapid decline²⁻⁵, and there is a global concern about the risk of
132 their extinction in the wild⁶⁻⁸. The main drivers of orangutan decline are the loss and degradation of forest
133 habitat, mostly for agricultural development²⁻⁵, and killing^{9,10}. Over the past 50 years, a diversity of
134 activities has been implemented to reduce and mitigate threats to orangutans^{11,12}. Which activities lead to
135 the best outcome, however, is subject to extensive debate^{13,14}. Furthermore, the species are distributed
136 across four regions (Sumatra and Kalimantan (Indonesia), and the Malaysian states of Sabah and Sarawak)
137 (Figure 1) with differential exposure to threats, heterogeneous biophysical and socioeconomic
138 characteristics, and diverse government policies. As a result, the extent to which the activities and the
139 concomitant funding are benefitting species persistence is unknown, as are the key externalities that shape
140 these benefits¹⁴.

141 We developed a comprehensive framework to assess the impact of conservation investments in wildlife
142 conservation across spatial and temporal scales. We applied this framework to investments in orangutan
143 conservation activities across Kalimantan, Sabah and Sumatra between 2000 and 2019. We collected data
144 on financial investments from private and public organizations involved in orangutan conservation in these
145 regions. The benefit of a given conservation activity was estimated as the improvement in the predicted
146 orangutan occurrence compared to the counterfactual of no activity. By comparing the spatiotemporally-
147 explicit investments with the estimated benefit, we evaluated the efficiency of two decades of investments
148 in six activities aiming to reduce orangutan population declines: (i) habitat protection and management, (ii)
149 habitat restoration, (iii) patrolling and law enforcement, (iv) rescue and rehabilitation, (v) translocation and
150 reintroduction, and (vi) public outreach and capacity building. The orangutan conservation Theory of
151 Change (ToC) pathways representing the chain of outcomes resulting from the conservation activities are
152 shown in Figures S1 and S2. The estimated investment in research on orangutans and their habitats
153 (excepting those exclusive to orangutan rehabilitation and translocation) was also quantified (Figure S3).
154 Through application of our framework to orangutan conservation, we were able to answer the following:
155 (1) Which conservation activities have been conducted, at what costs, and how were they distributed

156 spatially? (2) What was the net benefit of each conservation activity? (3) Within the contemporary range of
157 wild orangutan, which activities yielded the greatest return-on-investment, and how did this vary between
158 regions?

159 **Results**

160 **Investment in conservation activities for orangutans**

161 In the period between 2000 and 2019, the total nominal investment on orangutan-related conservation
162 activities across Kalimantan, Sumatra, and Sabah was US\$ 870 million. In real value, i.e., the nominal
163 value adjusted for inflation (see Methods), this equates to US\$ 1,16 billion. The annual average of the
164 nominal investment in the period 2015–2019 was US\$67 million, which was a nearly threefold increase
165 compared the annual average of US\$ 26 million from 2000–2005 (Figure 2a). The real value of investment
166 had increased 1.3 times (Figure 2a) and varied by region. Between 2000 and 2019, an average annual
167 operating expenditure valuing \$24-26 million had been allocated in both Kalimantan and Sabah, whereas,
168 in Sumatra, there was an average annual expenditure of \$8 million (Figures 2b and 3). Considering
169 regional differences in available habitat, Sabah had the greatest per unit habitat investment overall, with an
170 average annual operational expenditure of \$676 per km² of orangutan habitat (Figure 2c). Comparatively,
171 Sumatra invested \$272 per km² annually, whereas Kalimantan only invested \$85 per km² annually on
172 average.

173 The allocation of investments to different conservation activities differed between regions (Figure 4a). In
174 Kalimantan, the largest proportion of the total annual investment was assigned to habitat protection (31%),
175 followed by rescue and rehabilitation (18%) and public outreach (16%). In Sabah, patrolling and law
176 enforcement made up the largest proportion of the total annual expenditure (38%), followed by habitat
177 protection (20%) and outreach programs (15%). In Sumatra, a substantial proportion of the total annual
178 investment was allocated to habitat protection (47%), followed by patrolling (20%) and public outreach
179 (14%).

180 In Kalimantan, orangutan translocation and reintroduction programs were the most expensive activity
181 (\$427 per km²), while habitat protection was \$252 per km² (Figure 4b). In Sabah, patrolling was the most

182 expensive activity (\$1,303 per km²), double that of habitat protection. In Sumatra, habitat protection was
183 the most expensive approach (\$734 per km²), double that of patrolling activities. Sabah had the greatest
184 investment in research (\$407 per km² per annum) compared to less than \$150 per km² per annum in
185 Kalimantan and Sumatra.

186 **Benefits of conservation activities for orangutans**

187 Between 2000-2004 and 2015-2019, the mean probability of orangutan occurrence across the wild
188 orangutan contemporary range in Kalimantan, Sumatra and Sabah declined by approximately 20%. Based
189 on our analysis of the relationship between the species' probability of occurrence and density (Figure S4),
190 this translates to an estimated decline from 17.4 to 13.8 (95% confidence interval (CI): from 15.1-19.7 to
191 11.4-16.2) individuals per 5x5 km² grid-cell on average between 2000 and 2019 for Kalimantan, from 13.9
192 to 11.4 (95% CI: from 10.6-17.2 to 7.6-15.2) individuals per grid-cell for Sabah, and from 10.3 to 8.7 (95%
193 CI: from 7.9-12.7 to 6.3-11.1) individuals per grid-cell for Sumatra (Figure S4).

194 The benefit of a conservation activity was estimated by comparing the orangutan occurrence probability
195 (given existing conservation actions) with the counterfactual in the absence of conservation activity.

196 Across the three regions, habitat protection and patrolling were estimated to generate the greatest benefits
197 in maintaining orangutan occurrence (Figure 5a). In Kalimantan, habitat protection and patrolling were
198 associated with an average 13% and 3.6% improvements in the species' occurrence probability per 5x5
199 km² grid-cell every five years between 2000 and 2019 compared to the counterfactual of no investment in
200 these activities (Figure 5b). In Sabah, habitat protection and patrolling were estimated to improve
201 orangutan occurrence by 8.7% and 12% respectively, whereas in Sumatra they contributed to 16% and
202 12% improvements in occurrence respectively (Figure 5b). Besides these two conservation activities,
203 public outreach activities generated a large benefit for the orangutan populations in Sabah, providing 7.4%
204 improvement in the occurrence probability compared to the counterfactual of no outreach programs (Figure
205 5b).

206 **Return-on-investment of orangutan conservation activities**

207 The return-on-investment for a given orangutan conservation activity was estimated as the improvement in
208 the species' occurrence probability compared to the counterfactual in the absence of the activity divided by

209 the investment cost for that activity. Across Kalimantan, Sabah, and Sumatra and within the orangutan's
210 contemporary range, habitat protection was estimated to generate the highest return-on-investment overall,
211 providing an average 12% improvement in orangutan probability of occurrence per 5×5 km² grid-cell per
212 annual investment of US\$10,000 compared to the counterfactual (Figure 6a). Patrolling activities had
213 moderate benefit-per-dollar, providing a 9.2% improvement in orangutan occurrence probability.

214 There were variations in the return-on-investment of conservation activities across the different regions
215 (Figure 6b). In Kalimantan, habitat protection had the highest benefit-per-dollar (providing an average
216 improvement of 21% in the orangutans' probability of occurrence per 5×5 km² grid-cell per US\$10,000
217 annual investment compared to the counterfactual), followed by patrolling (9.4%). This translates to an
218 estimated density benefit of 7.4 orangutans per 25 km² for every annual spending of US\$10,000 for habitat
219 protection, and a density benefit of 3.2 orangutans for patrolling activities. In Sabah, outreach programs
220 had the highest benefit-per-dollar invested (average improvement of 6.1% in occurrence probability per
221 5×5 km² grid-cell per US\$10,000 annual investment compared to the counterfactual), followed by habitat
222 protection (5.3%). This translates to a density benefit of 2.2 orangutans per 25 km² for every annual
223 spending of US\$10,000 for each activity of outreach and habitat protection. In Sumatra, patrolling had the
224 highest benefit-per-dollar (average improvement of 16% in occurrence probability per 5×5 km² grid-cell
225 per US\$10,000 annual investment relative to the counterfactual). This translates to a density benefit of 2.3
226 orangutans per 25 km² for every annual spending of US\$10,000.

227 **Discussion**

228 **Implications for orangutan conservation policies in different regions**

229 *Kalimantan*

230 In Kalimantan, habitat protection produced the best outcome in reducing the decline in orangutan
231 probability of occurrence (Figure 5b). Large-scale forest loss and the expansion of industrial agriculture,
232 especially in unprotected lands (in non-state-forest zones and forest areas designated for land clearing and
233 conversion to agro-industries) occurred at rapid rates, especially between 2005 and 2015¹⁵. These lowland
234 areas typically co-occur with orangutan populations, and without forest protection extensive areas of

235 orangutan habitats and subsequently large populations of orangutans would have been lost. The average
236 investment per km² for habitat protection in Kalimantan was generally lower than in Sumatra and Sabah
237 (\$252 per km², versus \$734 and \$664 per km² for Sumatra and Sabah respectively) (Figure 4b), reflecting
238 Kalimantan's earlier stage of development compared to the other two regions¹⁶. Consequently, habitat
239 protection by government, companies or rural communities was considered to provide an excellent return-
240 on-investment in reducing the decline in orangutan occurrence (Figure 6b).

241 Annual spending on translocation and reintroduction in Kalimantan had increased fourfold since 2000
242 (from \$0.7 million in 2000 to \$2.8 million in 2019) (Figure S5), and this reflects the growing application of
243 this conservation tool in response to increasing land pressure. Rapid large-scale deforestation over the past
244 20 years has led to escalated negative interactions between humans and wild orangutans^{4,5,10}. Rescue and
245 translocation of orangutans to conservation areas or protected forests have provided readily implementable
246 actions to remove animals from immediate danger arising from such negative interactions. Removing
247 orangutans and translocating them to large forest blocks deemed more suitable for their survival may seem
248 straightforward and is often presented as an efficient conservation tool, particularly when alternative
249 conservation activities may require planning and extensive negotiation with multi-sectoral and multi-level
250 stakeholders¹⁷. However, the relative success of this conservation approach is still not known and might be
251 relatively low and there is a potential negative impact of these exercises on the viability of metapopulations
252¹⁷. Furthermore, translocation and reintroduction can be costly and are associated with high mortality rates
253¹⁸. In Kalimantan, translocations were the most expensive conservation activities in terms of operational
254 cost per km², and the cost greatly exceeds those in other regions (\$427 per km², versus \$41 and \$121 per
255 km² for Sabah and Sumatra) (Figure 4b).

256 The number of orangutans residing outside of protected areas is substantial in Kalimantan^{4,5}. Hence,
257 continuing land clearing in this region is anticipated to lead to frequent negative interactions between
258 orangutans and people, and potentially higher prevalence of orangutan removal. An ongoing and increasing
259 focus on translocation and reintroduction programs in Kalimantan could potentially undermine the
260 allocation of funding to other activities with substantially higher and lasting benefits such as habitat
261 protection, patrolling, and outreach programs. There is a need to seek solutions that would enable

262 orangutans and people to co-exist, such as better land use planning through creation of buffer zones
263 separating orangutan habitats and rural settlements and improved partnership between conservation actors
264 and rural communities in building relationships of reciprocity, acknowledgment, and care ¹⁹.

265 The expenditure cost per square kilometre for habitat protection in Kalimantan was generally lower than in
266 other regions (Figure 4b), suggesting that it is relatively inexpensive to effectively reduce orangutan
267 declining rates through this action. Habitat protection is therefore a worthy investment to pursue to allow
268 orangutans to remain in their native habitats in this region. Further, given that the current conservation
269 expenditure per square kilometre of orangutan habitat in Kalimantan is substantially lower than in other
270 regions (Figure 2c), increasing the amount of investment for habitat protection here could potentially
271 reduce the orangutan declining rates significantly.

272 The costs associated with patrolling activities in Kalimantan were \$155 per km² and significantly lower
273 than in other regions (\$1,303 and \$302 per km² for Sabah and Sumatra respectively), whereas outreach
274 programs were \$93 per km² and also lower than in other regions (\$491 and \$204 per km² for Sabah and
275 Sumatra) (Figure 4b). This is likely because human population density, remuneration rates and market
276 influence in Kalimantan are generally lower compared to other regions ¹⁶. Larger investments can therefore
277 potentially be allocated to these activities to monitor, prevent negative human-wildlife interactions, and
278 assist rural communities living within close proximity to forests inhabited by orangutans ¹⁴. Local
279 communities are also likely to benefit from maintaining forest cover, as forests can support and sustain the
280 flow of ecosystem services and provide benefits to broader community wellbeing (e.g., by preventing soil
281 erosion and floods, and regulating air quality) ²⁰⁻²².

282 ***Sabah***

283 In Sabah, patrolling produced the best outcome in reducing the decline in orangutan occurrence
284 probability, followed by habitat protection (Figure 5b). During the study period, the Sabah government
285 increased the size of protected areas from 12% to nearly 30% of the state land area ^{23,24}, and, by 2020, more
286 than 70% of orangutans in Sabah were found inside protected areas ^{17,23}. This is quite different from the
287 situation in Indonesia where most terrestrial protected areas were established before 2005 (currently

288 covering 23% of the total land area for Kalimantan and Sumatra), and the expansion of forest protection
289 since 2005 was mainly through the establishment of community-based land tenure and acquisition of
290 private land by conservation NGOs. Consequently, a high level of investment specifically from the Sabah
291 government has been allocated to resource-intensive patrolling activities for these protected areas, but
292 lower investment had been allocated to habitat protection since all these new areas were gazetted by the
293 government without incurring any high significant direct cost or land purchase for their creation.
294 Significantly higher baseline remuneration rates in Malaysia compared to Indonesia^{25,26} have also likely
295 contributed to the high cost associated with patrolling activities.

296 Public outreach programs, community engagement and capacity building also provided benefits to
297 protecting orangutan populations in Sabah (Figure 5b), and these programs were mainly carried out by
298 various state agencies and their NGO partners. Despite higher operational cost per square kilometre for
299 public outreach in Sabah than in Kalimantan and Sumatra (\$491 per km², versus \$93 and \$204 per km² for
300 Kalimantan and Sumatra) (Figure 4b), the activity provided the best return-on-investment in terms of
301 orangutan occurrence benefits (Figure 6b). Unlike in Kalimantan and Sumatra, there has been limited
302 change in land cover in Sabah over the past 20 years as deforestation had mostly occurred before 2000¹⁵.
303 Consequently, only a low number of orangutan individuals were displaced and required rehabilitation or
304 translocation between 2000 and 2019, and this explains why the expenditures for rehabilitation and
305 reintroduction programs were small (Figure 4).

306 *Sumatra*

307 In Sumatra, habitat protection produced the best outcome in reducing the decline in the orangutan's
308 probability of occurrence, followed by patrolling activities (Figure 5b). However, the cost of habitat
309 protection was expensive compared to the cost of other activities in the region, and compared to habitat
310 protection in other orangutan regions in Indonesia (\$735 per km², versus \$252 per km² for Kalimantan)
311 (Figure 4b). This is likely attributed to the higher opportunity cost of land for conversion to agriculture,
312 and the cost associated with establishing and managing land in this relatively developed region¹⁶. During
313 the study period, several land acquisitions and their protection occurred across the orangutan range in
314 Sumatra (e.g., within the Leuser Ecosystem). Such initiatives, consequently, incurred significant direct

315 costs on land purchase and management establishment. Despite providing the highest benefit on orangutan
316 occurrence (Figure 5b), due to the high land-related cost (Figure 4b) the protection strategy was considered
317 less efficient in terms of monetary value (Figure 6b). On the other hand, the costs of patrolling were
318 moderate (\$302 per km²), which is higher than in Kalimantan (\$155 per km²) but substantially lower than
319 in Sabah (\$1,303 per km²) (Figure 4b). This could be partly due to the lower baseline remuneration rates in
320 Indonesia compared to Malaysia, despite baseline prices of goods in both countries being relatively similar
321 ^{25,26}. Due to the moderate costs for patrolling, this activity provided the best return-on-investment in terms
322 of orangutan occurrence benefit in Sumatra (Figure 6b).

323 Rescue and rehabilitation activities provided only a small benefit for maintaining the probability of
324 occurrence of orangutans in their range (i.e., they provide limited deterrence to poaching and trafficking),
325 and this is similar to the presence of reintroduction sites and outreach activities in the island (Figure 5b).
326 Similar to the situation in Sabah, the investment in rehabilitation activities in Sumatra was minor (Figure
327 4), hence the return-on-investment for probability of occurrence has limited applicability.

328 **Caveats and limitations**

329 There are four key limitations in our analysis. The first pertains to the accuracy of our investment dataset.
330 While we attempted to comprehensively collect information on all investment, it is likely that we missed a
331 few. Additionally, in some instances, detailed information on the amount of investment for different
332 activities for a particular organization was not available. To overcome this issue, we estimated activity
333 expenditure amounts based on the activities described in the organization's reports or website and the costs
334 of those activities undertaken by similar-sized organizations operating in the same region for which we had
335 specific data. The second limitation is associated with the modelling approach and the implications on the
336 estimation of conservation benefits. We assumed that the effect of a conservation activity on orangutan
337 presence can be adequately captured in the model mainly through variable distance to the location of that
338 conservation program as a proxy (see Methods). As such, in a grid-cell where multiple activities are
339 operating simultaneously with different levels of importance (e.g., patrolling is carried out with higher
340 efforts than public outreach programs), the model assumes equal importance of all actions. As research
341 programs usually co-occur simultaneously with other conservation activities, the impact of research is

342 difficult to estimate accurately through our modelling approach. This was the reason why we excluded
343 research from the cost-benefit analysis. The third limitation relates to the methodology for constructing the
344 counterfactual scenarios. We applied the most sensible, relevant and practical approach for defining the
345 counterfactuals. In reality, these counterfactual scenarios are much more complicated and influenced by
346 multiple biophysical and socioeconomic factors²⁷. The fourth limitation pertains to province-level
347 differences in threats and government policies in Indonesia. Our cost-benefit analyses were aggregated to
348 provide general and broad island-based inference to inform national policies. Province-level analysis
349 would likely generate more nuanced outcomes from the modelling output to guide local policy at the sub-
350 island level. We have tried to adequately address these limitations wherever possible and are convinced
351 that despite these caveats the results of the analysis reflect appropriately the situation on the ground.

352 **Conclusions and recommendations**

353 Judicious planning for conservation under a constrained budget requires an understanding of the dynamics
354 of conservation investments and activities and how they relate to species trends across their spatial range.
355 Such an analysis is however rarely conducted, as it requires comprehensive spatiotemporally explicit data
356 on the species, the natural environment and threats, conservation activities, investments in these activities,
357 and an estimation of the counterfactual situation without the investment. Using orangutans as a case study,
358 our analysis estimated that habitat protection, patrolling and public outreach provided large benefits in
359 slowing down the decline in orangutan numbers. However, given variability in threats and development
360 circumstances and stages in different regions where orangutans occur, the most cost-effective conservation
361 activity was different across regions. Our findings highlight the importance of accounting for regional
362 differences in land pressure and socioeconomic elements to guide the focus of investment in different areas
363 and contexts to achieve the desired conservation goals.

364 We recommend the application of our findings in planning for future funding and policy strategies for
365 orangutan conservation to ensure optimal use of limited resources and apply the analytical framework to
366 the conservation of other wildlife. It would be highly beneficial for orangutans and other species if data on
367 their distribution and densities and detailed information on conservation programs, (i.e., where are they
368 conducted and when, what kind of activities specifically involved, and how frequent these activities are

369 conducted) could be transparently and centrally coordinated, made publicly available, and regularly
370 updated by participating organizations working in species conservation. Such transparency on spending
371 could help facilitate open discussions about improving the existing strategies.

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381 **Author contributions**

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390 **Declaration of interests**

391 The authors declare no competing interests.

392

393 **Main-text figure titles and legends**

394 **Figure 1. Islands covering the orangutan range.**

395 Sumatra, Indonesia (470,000 km²) and Borneo (including Kalimantan, Indonesia and Sabah and Sarawak,
396 Malaysia) (740,000 km²). See also Figure S4.

397

398 **Figure 2. Changes in nominal and real investments into orangutan conservation over time and by**
399 **region.**

400 (A) Total investment (nominal and real value, in US\$) spent annually on orangutan-related conservation
401 activities across Kalimantan, Sabah and Sumatra. (B) The annual total real expenditure of conservation
402 activities, and (C) per km² of orangutan habitat, broken down by region. Conservation activities assessed
403 include the six core activities in which the impacts on orangutan survival may be captured over a short
404 time period (five years): habitat protection, habitat restoration, patrolling and law enforcement, rescue and
405 rehabilitation, translocation and reintroduction, and public outreach and capacity building, and research-
406 related activities considered influencing conservation and land use management decision in the long term.

407

408 **Figure 3. The change in the distribution of investment to orangutan conservation in Borneo and**
409 **Sumatra, aggregated to sub-district level.**

410 Values inside the parenthesis represent the annual total real expenditure for a given period and region. In
411 the first period (2000-2004), investments in Borneo were focused in Sabah and spread across the orangutan
412 range in West, Central and East Kalimantan. Investments in later periods gradually became clustered more
413 around orangutan sanctuaries near the Gunung Palung, Tanjung Puting, Sebangau, and Kutai National
414 Parks and the interior part of Borneo. In Sumatra, the main increase in investment was in the Jantho Nature
415 Reserve at the northern part of the island and Batang Toru. Relates to Figure S5.

416

417 **Figure 4. Expenditure allocation to different strategies.**

418 (A) Proportion of total expenditure allocated to different conservation activities, and (B) mean annual real
419 expenditure for different activities (US\$ per km²) broken down by region. The costs of conservation
420 activities assessed include the six core activities considered affecting the orangutan survival in the short
421 term (five years): habitat acquisition and protection (PROTECT), habitat restoration (RESTORE),
422 patrolling and law enforcement (PATROL), rescue and rehabilitation (REHAB), translocation and
423 reintroduction (REINTRO), and public outreach and capacity building (OUTREACH), and research-
424 related activities considered influencing orangutan persistence in the long term (RESEARCH). See also
425 Figure S5.

426

427 **Figure 5. The benefit of six orangutan conservation activity within the wild orangutan contemporary**
428 **range.**

429 (A) estimated by comparing the orangutan probability of occurrence (given existing conservation actions)
430 with the counterfactual in the absence of conservation activity, (a) averaged across the three regions, and
431 (B) individually by region. Conservation activities evaluated include the six core activities: habitat
432 protection (PROTECT), habitat restoration (RESTORE), patrolling and law enforcement (PATROL),
433 rescue and rehabilitation (REHAB), translocation and reintroduction (REINTRO), and public outreach and
434 capacity building (OUTREACH). Research-related activities (RESEARCH) was excluded from the
435 benefit analysis as it is considered to primarily influence conservation actions and land use management
436 decisions in the long term. See also Figure S4.

437

438 **Figure 6. Return-on-investment of six orangutan related conservation activities.**

439 Defined as the percentage improvement in orangutan probability of occurrence per 5x5 km² per US\$10,000
440 investment. (A) overall across the three regions, and (B) broken down by region. Conservation activities
441 assessed include the six core activities: habitat protection (PROTECT), habitat restoration (RESTORE),
442 patrolling and law enforcement (PATROL), rescue and rehabilitation (REHAB), translocation and
443 reintroduction (REINTRO), and awareness raising, capacity building and policy (OUTREACH). Research-
444 related activities (RESARCH) was excluded from the return-on-investment analysis as it is considered as
445 primarily influencing conservation actions and land use management decisions in the long term.

446 **STAR Methods**

447 **Resource availability**

448 **Lead contact**

449 Further information and requests for resources should be directed to and will be fulfilled by the lead
450 contact, Truly Santika (T.Santika@greenwich.ac.uk).

451 **Materials availability**

452 This study did not generate new unique reagents.

453 **Experimental model and subject details**

454 We collected data on orangutan conservation investments across Borneo and Sumatra for the period 2000–
455 2019, based on the most recent yearly budget allocations available, comprising a total of 259 investments.

456 We identified initial lists of organizations that were carrying out orangutan conservation activities. An
457 organization was considered conducting orangutan conservation activities if it met two criteria:

458 1) the goals or conservation activity descriptions specifically mentioned orangutans, or in the case of
459 habitat conservation activities orangutans were specifically mentioned in relation to the affected
460 habitat; and

461 2) the orangutan-related conservation activities were conducted on the ground in the orangutan range
462 regions (Borneo and Sumatra) regardless of where the organization was headquartered.

463 For every investment, we recorded the entity or organization managing the conservation activity, the sector
464 of the entity (e.g., government agency, non-government organization (NGO), and rescue centres), the
465 location where the activity had taken place, the allocation of funds spent on each category of conservation
466 activities during the latest available financial year (see below), the years between 2000 and 2019 when the
467 activities were undertaken, and the investment amount.

468 Other data used are detailed in the Key Resources Table.

469 **Method details**

470 Our study framework consists of four steps of analyses: (1) collating data on conservation investments; (2)
471 modelling the change in the distribution of the species under study; (3) estimating the benefit of
472 conservation activities on that species through changes in the species occurrence; and (4) estimating the
473 return-on-investment.

474 Our study area covers the orangutan range in the island of Sumatra, Indonesia (470,000 km²) and Borneo
475 (including Kalimantan, Indonesia and Sabah, Malaysia) (740,000 km²) (Figure 1). We excluded the
476 Malaysian state of Sarawak, as we have insufficient data on orangutan surveys and conservation
477 investment in this region. The orangutan range in Sarawak is small compared to the overall orangutan
478 range and leaving out Sarawak should not affect our overall findings. For the spatial unit of analysis, we
479 used a grid-cell with a resolution of 5×5 km². This resolution corresponds to the average home range of
480 adult male orangutans, which overlaps with the home range of several females²⁸. As the temporal unit of
481 analysis, we used four time periods: 2000-2004, 2005-2009, 2010-2014, and 2015-2019.

482 *Collecting data on conservation investments*

483 We collected investment data through direct communications with identified organizations, and via
484 desktop research and review of publicly available data on each organization's expenditure reports (i.e.,
485 grant and project databases, corporate sustainability reports, annual reports, budgets and financial reports,
486 tax filings of donors and implementing organizations and charity commission reports, and organization
487 websites) (see Tables S1 and S2 for the source of information on investment and the list of organizations or
488 entities). To avoid double counting investments from both donors and implementers, we only used data on
489 investments made by organizations implementing orangutan conservation activities on the ground in
490 orangutan habitat.

491 Where an organization's investment amounts by activity were not specified (data were only available on
492 the overall amounts), we looked for data from any project grants related to orangutan conservation the
493 organization received where amounts spent on specific activities were detailed. Where no detailed data was
494 available for a given organization, we estimated activity expenditures amounts based on the activities

495 described in the organization's reports or website, and the costs of those activities undertaken by similar-
496 sized organizations operating in the same region for which we did have specific data. We tested these
497 estimations for accuracy by requesting selected organizations to check our figures for their budgets. For
498 government-funded habitat protection activities, we also included community-based forest management,
499 especially the *Hutan Desa* (Village Forest) scheme in Indonesia. We only included *Hutan Desa* areas
500 where the boundaries overlap with the orangutan range. We used an estimated cost of US\$50 per ha for
501 establishing *Hutan Desa*²⁹. For oil palm concessions certified under the Roundtable on Sustainable Palm
502 Oil and timber concessions certified under the Forest Stewardship Council where no sustainability
503 investment was specified, we estimated that US\$10 per ha (RSPO) or US\$1 per ha (FSC) was spent on
504 HCV areas. These averages were based on data from several companies for which we had more detailed
505 information on investment per unit area. The expenditure data we collected from various organization
506 reports and databases were mostly in US\$ (US Dollar). The amounts of spending in a given year originally
507 provided in national currencies (Indonesian Rupiah and Malaysian Ringgit) were converted to US\$ using
508 the currency conversion rate applicable to that year.

509 We categorized organizations into six sectors: (1) government, including agencies, national parks, and
510 government-funded community-based forest management; (2) bilateral or multilateral bodies; (3) non-
511 governmental organizations (NGOs); (4) rescue centres, including sanctuaries for care of orphaned or
512 seized wildlife, (5) commercial corporations including industrial agriculture, timber and pulp, logging, and
513 mining; and (6) research centres and universities. For commercial corporations, oil palm plantation
514 companies certified by the Roundtable for Sustainable Palm Oil (RSPO) that spent funds to maintain High
515 Conservation Value lands which were known to have orangutans (based on the overlap with the species'
516 ranges) were included even if the company reports did not specifically mention orangutan conservation.
517 We did the same for timber plantations and logging companies certified by the Forestry Stewardship
518 Council (FSC). This is because both RSPO and FSC require the conservation values (including orangutans)
519 in the concession to be maintained, and independent audits are carried out to verify this^{30,31}. We assumed
520 that uncertified plantations, logging, or mining concessions did not invest in orangutan conservation unless
521 our review of orangutan investment information identified them specifically as doing so. For research,
522 funding for local studies of orangutans by researchers (local and foreign) was counted if: (1) the research

523 was part of the work of an in-situ research centre focused on orangutans or including orangutan studies,
524 and the studies met both criteria mentioned above; or (2) the research project came up in search results for
525 orangutan conservation investments and met both our criteria. Investments in orangutan habitat range by
526 government agencies with direct management authority for orangutans or any orangutan habitat areas were
527 included regardless of orangutan mentions.

528 For missing annual data on investment, we estimated the amount of spending by fitting an Ordinary Least
529 Square (OLS) regression model to the available data covering different years. For an entity with limited
530 investment data, we estimated the overall investment envelope based on the trends captured in similar-
531 sized organizations. For NGOs and rescue centres, we identified a consistent pattern of a 2-3% increase in
532 annual expenditure for orangutan conservation between 2000 and 2019 across Indonesia and Malaysia.
533 Similarly, we identified a 4-5% increase in government's annual expenditure for orangutan conservation
534 over the same period in Malaysia and wildlife conservation activities in general for Indonesia. For that
535 reason, we applied 2.5% and 4.5% annual increases for missing NGO data and missing government data,
536 respectively.

537 *Allocating investment data to activities*

538 Expenditure data by individual activities were not consistently available from all orangutan conservation
539 entities, hence we grouped similar activity types into the six broad categories described below. For each
540 investment unit, we first recorded the entity, entity sector, the location where the entity was operating, and
541 funds spent during the latest available financial year on six categories of conservation activities based on
542 the Conservation Measures Partnership Action Classifications³². Six categories of activities related to
543 orangutan conservation were identified across the three regions. The classification of activities were
544 informed by the Conservation Measures Partnership³² and include: (1) habitat protection and acquisition
545 (PROTECT); (2) habitat restoration (RESTORE); (3) patrolling and law enforcement (PATROL); (4)
546 rescue and rehabilitation (REHAB); (5) translocation and reintroduction (REINTRO); and (6) public
547 outreach and awareness raising, capacity building and policy (OUTREACH) (Figures S1 and S2). Besides
548 these six core activities, we also estimated investment in research activities that may influence

549 conservation and land use management decisions (RESEARCH) (Figure S3). Details about the activity
550 categories are as follows:

- 551 1) Habitat protection and acquisition (PROTECT), includes management and maintenance of the
552 land, such as firefighting, invasive plant or animal control, fencing or other infrastructure related to
553 protection, avoided deforestation payments or costs, habitat purchase, community land reserves or
554 forestry including payment to communities to establish protection;
- 555 2) Habitat restoration (RESTORE), includes replanting, growing nursery stock, maintenance of
556 restored forest by watering, and other activities needed to establish and maintain restored habitat;
- 557 3) Patrolling and law enforcement (PATROL), includes rangers and wardens and their associated
558 expenses, infrastructure like guard posts, patrol equipment, prosecution, and incarceration costs;
- 559 4) Rescue and rehabilitation (REHAB), includes activities related to intake, captive care and
560 rehabilitation of orangutans;
- 561 5) Orangutan reintroduction and translocation (REINTRO), includes orangutan releases, post-release
562 monitoring and research to identify release sites or release outcomes. Orangutan releases include:
563 (a) the release of rehabilitated ex-captive orangutans to reinforce existing wild populations; (b)
564 reintroduction of populations within historic range but outside the current distribution; and (c)
565 removal and subsequent release of wild orangutans considered an immediate or potential threat to
566 humans and human activities, or where the orangutans are themselves threatened by humans and
567 human activities; and
- 568 6) Public outreach, awareness raising, capacity building and policy (OUTREACH), includes
569 community outreach, training and capacity building for environmentally friendly livelihoods and
570 human-orangutan conflict mitigation, policy development or advocacy on orangutan conservation
571 related issues.

572 An additional expenditure category of administrative and overhead costs (costs for operation of the entity
573 rather than the implementation of activities) was excluded from our model. Although the cost of operating

574 the organizations, businesses and agencies is vital to the ability to deliver the orangutan conservation
575 activities, and represents millions more dollars spent annually, these expenditures did not meet our criteria
576 of conservation activities implemented within orangutan range.

577 *Orangutan conservation Theory of Change (ToC) pathways*

578 The Theory of Change (ToC) pathways for each orangutan conservation activity (Figures S1, S2 and S3)
579 represent the chain of outcomes resulting from the conservation activities within the short term (five years
580 after the activity is initiated) and long term (more than five years after initiation) that can lead to reduced
581 threats and positive impacts on species population trends. We considered the short term, five-year time
582 interval in the ToC to conform to the data analysis and modelling approach we used. Under this ToC
583 framework, it is assumed that PROTECT actions establish land regulation, management and enforcement
584 to prevent habitat degradation and poaching. RESTORE actions facilitate forest regrowth, either through
585 active restoration (e.g., reforestation and hydrological rehabilitation) or passive restoration (natural
586 regeneration). The presence of PATROL activities helps reduce wildlife and forest crimes, and law
587 enforcement actions can further establish this deterrence. REHAB includes the transfer of animals seized
588 by authorities, a preliminary step in a legal process that, when it culminates in sanctions, can deter crime.
589 Additionally, REHAB actions provide opportunities for releasable animals to become part of a successful
590 release program. REINTRO actions facilitate orangutans released into natural habitats where they can
591 improve the viability of existing wild populations or establish new viable populations. REINTRO actions
592 can also pose real disease, genetic and behavioural risks to wild orangutan populations, and thus have the
593 potential to have both positive and negative impacts on the species. OUTREACH actions assist
594 communities in mitigating human-orangutan conflicts and supporting behavioural changes to facilitate
595 coexistence between orang-utan and people and support conservation of orangutans and their habitats.

596 Unlike these six core conservation activities whereby the benefits on orangutan survival are likely to be
597 realized over the short term (within five years period), RESEARCH activities may take longer time to
598 benefit orangutans. Most research consists of several stages of activities (e.g., field survey and data
599 collection, data analysis, and consultation with different stakeholders) that may take several years to
600 produce findings to inform or provide recommendations for conservation actions and policies. These

601 policy recommendations subsequently may take several more years to be implemented and therefore begin
602 to benefit the species. Nonetheless, research sites whereby researcher presence is maintained over the long
603 term are recognized to have a deterrent effect on poaching and forest crimes³³.

604 *Orangutan survey data*

605 We used an existing database of orangutan survey data from 2000 to 2015^{2-5,17,34,35} and new survey data
606 from 2015 to 2019, from both Borneo and Sumatra. These data consisted of: (a) orangutan nest encounters
607 obtained from transects surveys, both on the ground and from aerial surveys (occupied aircraft and drones);
608 (b) orangutan or nest encounters obtained from reconnaissance or opportunistic surveys; and (c) sightings
609 of orangutans reported by village residents through interviews. To reduce potential false detection of
610 orangutans in the interview data, we selected only villages where more than 30% of respondents reported
611 orangutan sightings as an indicator of orangutan presence. For each time period, any 5×5 km² grid-cell
612 with orangutan sightings or nest encounters was assigned “presence”, whereas grid-cells with one survey
613 or more without any sightings of orangutans or nests was assigned “absence”. Absence records in a grid-
614 cell for a given time period can therefore represent real absence (the species never occurred in that grid-
615 cell) or loss (the species used to be present in that grid-cell, but not anymore). Grid-cells without any
616 survey were excluded in the model building.

617 **Quantification and statistical analysis**

618 *Inflation-adjusted value of investment*

619 The investment data represent the nominal value of investment. To obtain the real value of investment to
620 facilitate intra-country comparison and discern the actual purchasing power of organizations in
621 implementing activities on the ground across different regions, we adjusted the nominal value with
622 inflation rates³⁶. Inflation rates have changed dramatically in Indonesia and Malaysia between 2000 and
623 2019 (<https://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG>). The consumer price indices (CPI) in
624 both countries are similar and therefore were not employed in the adjustment. The real value of investment
625 in time period 2000-2004 ($t=1$), 2005-2009 ($t=2$), and 2010-2014 ($t=3$) can be expressed in reference to the
626 present period 2015-2019 ($t=4$), i.e.

627 $\hat{C}_t = C_t \times (r_1 + 1)^{5 \times b_1} \times (r_2 + 1)^{5 \times b_2} \times (r_3 + 1)^{5 \times b_3}$

628 with $(b_1, b_2, b_3) = (1, 1, 1)$ if $t=1$,

629 $(b_1, b_2, b_3) = (0, 1, 1)$ if $t=2$, or

630 $(b_1, b_2, b_3) = (0, 0, 1)$ if $t=3$.

631 where \hat{C}_t is the real value of investment at time period t relative to the present period; C_t is the nominal
632 value of investment at time period t ; and r_1 , r_2 and r_3 is the average inflation rates for time period $t=1$, $t=2$,
633 and $t=3$, respectively.

634 We aggregated the yearly investment data into four time periods to conform to the baseline time interval
635 used in the orangutan occurrence change analysis: 2000-2004, 2005-2009, 2010-2014, and 2015-2019. We
636 also calculated the estimated investment in each 5×5 km² grid-cell for each of the six activities plus
637 investments into orangutan-related research.

638 ***Modelling the change in species distributions***

639 We used the Generalized Boosted Regression Modelling (GBM) approach³⁷ to fit the orangutan presence-
640 absence data for each of the four time periods for each orangutan region (i.e. Kalimantan, Sabah, and
641 Sumatra) using 15 environmental predictors (Table S3). These regional divisions were chosen to account
642 for the broad threat and socioeconomic patterns and government policies at the national and island levels.
643 The environmental predictors included static variables over the timeframe of interest, such as elevation,
644 long-term mean monthly rainfall during the dry and wet months, distance to nearest city, and percentage of
645 peatland, and dynamic variables (with changing spatial configurations over the different time periods t),
646 including forest cover ($FORST_t$), percentage of degraded peatland (<30% forest cover) ($DEGPT_t$), distance
647 to nearest industrial oil palm plantation, and distance to conservation activities that are considered to be
648 delivering benefits to orangutans. These conservation activities included forest protection through the
649 establishment of protected areas (including national parks, nature reserves, watershed protection forest, and
650 community-based forest management) ($PRTCA_t$), patrolling activities ($PTROL_t$), rehabilitation centres
651 ($RHCTR_t$), orangutan translocation and reintroduction sites ($RINTR_t$), and orangutan-related public

652 outreach and awareness raising (*COMRC_t*). To control for spatiotemporal effects of survey protocols on
653 orangutan presence reports, we included survey effort (i.e., the number of surveys on orangutans conducted
654 in each grid-cell) and distance to orangutan research centres or activities as predictor variables. All
655 predictor variables were weakly correlated.

656 For each regional-based GBM model, we estimated the model parameters (Figure S6) and the change in
657 the probability of occurrence of orangutans through the four time periods in each region. The baseline
658 probabilities of occurrence differed between regions. To standardize the change in occurrence across the
659 different regions, and to provide a practical representation of the population change through time to inform
660 policy, we translated the probability of occurrence data to density estimates. This was done by assessing
661 the correlation between the predicted orangutan probability of occurrence (generated from the GBM) and
662 the density rates calculated directly from the orangutan transect dataset over grid-cells where transect
663 surveys were conducted (Figure S4).

664 ***Estimating the benefit of conservation activities and the return-on-investment***

665 The counterfactual scenario, reflecting the absence of conservation activity between 2000 and 2019, was
666 calculated by estimating how each activity modifies the predictor variables in the GBM models. The
667 association between the outcome potentially generated from each activity and the predictor variables was
668 informed by the orangutan conservation Theory of Change (ToC) pathways (Supplementary Data; Figures
669 S1 and S2). The habitat protection strategy (PROTECT) is assumed to affect forest loss and ecosystem
670 protection more broadly²⁰. Our analysis suggested that areas assigned to protected areas were able to halve
671 deforestation rates (compared to the rates within 50 km of the protected area boundaries) in Borneo and
672 reduce deforestation rates by a quarter in Sumatra (Figure S7A), and this is likely because pressure to
673 convert forest to other land uses was stronger in Sumatra than in Borneo overall^{16,38}. Hence, the
674 counterfactual scenario in the absence of PROTECT assumes that: (a) the counterfactual forest loss rates
675 inside protected areas were roughly twice or four times the actual rates for Borneo and Sumatra
676 respectively (i.e. $FORST_{t,counterfactual} = FORST_0 - (r \times FLOSS_t)$, and $FORST_{t,counterfactual} = FORST_{t-1,counterfactual}$
677 $- (r \times FLOSS_t)$ for $t > 1$, where $r=2$ for Borneo and $r=4$ for Sumatra), (b) the counterfactual percentage of
678 degraded peatland (<30% forest cover) inside protected areas ($DEGPT_{t,counterfactual}$) is higher than the actual

679 ($DEGPT_t$); and (c) the counterfactual distance to forest protection was the actual distance multiplied by 100
680 (i.e. $PRTCA_{t,counterfactual} = PRTCA_t \times 100$), thus forest protection having negligible effect.

681 The habitat restoration strategy (RESTORE) is assumed to affect forest gain. Our analysis suggested that
682 areas assigned to habitat restoration in Borneo and Sumatra were able to increase forest cover twice the
683 rate outside habitat restoration areas (Figure S7B). Hence, the counterfactual scenario in the absence of
684 RESTORE assumes that the counterfactual forest gain inside restoration areas was half the actual forest
685 gain (i.e. $FORST_{1,counterfactual} = FORST_0 + (0.5 \times FGAIN_1)$, and $FORST_{t,counterfactual} = FORST_{t-1,counterfactual} +$
686 $(0.5 \times FGAIN_t)$ for $t > 1$).

687 For conservation activities such as patrolling and law enforcement (PATROL), rescue and rehabilitation
688 (REHAB), translocation and reintroduction (REINTRO), and outreach and advocacy (OUTREACH), the
689 counterfactual scenario in the absence of the activity assumes that the counterfactual distance to the
690 activity was the actual distance multiplied by 100 (i.e. $PTROL_{t,counterfactual} = PTROL_t \times 100$ for PATROL,
691 $RHCTR_{t,counterfactual} = RHCTR_t \times 100$ for REHAB, $RINTR_{t,counterfactual} = RINTR_t \times 100$ for REINTRO, and
692 $COMRC_{t,counterfactual} = COMRC_t \times 100$ for OUTREACH). Our analysis suggested that deforestation rates in
693 areas with PATROL, REINTRO, or OUTREACH activities were similar to the rates in areas without such
694 activities. Therefore, we assumed that the counterfactual forest cover is the same as the actual.

695 The benefit of each conservation activity in each 5×5 km² grid-cell was estimated as the percent
696 improvement in the orangutan probability of occurrence compared to the counterfactual scenario. Specific
697 for the translocation and reintroduction strategy (REINTRO), we further multiplied the benefit by 50%.
698 This is considering that post-release mortality rates of orangutan individuals in new translocation areas can
699 range widely between 20% and 80%^{18,39,40}, thus the median value of 50% was chosen. In calculating the
700 benefit, we focussed only on activities that had occurred within the contemporary ranges of wild
701 orangutans, therefore excluded reintroduction sites outside the orangutan range such as the Jantho Nature
702 Reserve and Bukit Tigapuluh National Park in Sumatra.

703 Return-on-investment from orangutan conservation activity in each 5×5 km² grid-cell was estimated as the
704 benefit of conservation activity in improving orangutan probability of occurrence compared to the

705 counterfactual scenario divided by the cost of activity in that grid-cell. The conservation activities with the
706 largest return-on-investment will deliver the largest improvements in orangutan occurrence per dollar.

707 **Data and code availability**

- 708 • The raw investment data and orangutan survey data reported in this study cannot be deposited in a
709 public repository because of confidentiality issues. To request access, ask the lead contact for
710 contact information for the entities listed in Tables S1 and S2. In addition, processed datasets
711 derived from these data have been deposited at the APES database (<http://apesportal.eva.mpg.de/>)
712 and will be publicly available as of the date of publication. Accession numbers or DOIs are listed
713 in the Key Resources Table.
- 714 • This paper analyzes existing, publicly available data. The accession numbers for the datasets are
715 listed in the Key Resources Table.
- 716 • All non-confidential data reported in this paper will be shared by the lead contact upon request.
- 717 • All original code is available in this paper's supplemental information.
- 718 • Any additional information required to reanalyze the data reported in this paper is available from
719 the lead contact upon request.

720 **R code**

721 All original code has been deposited at DOI: 10.5281/zenodo.6080322 and is publicly available as of the
722 date of publication.

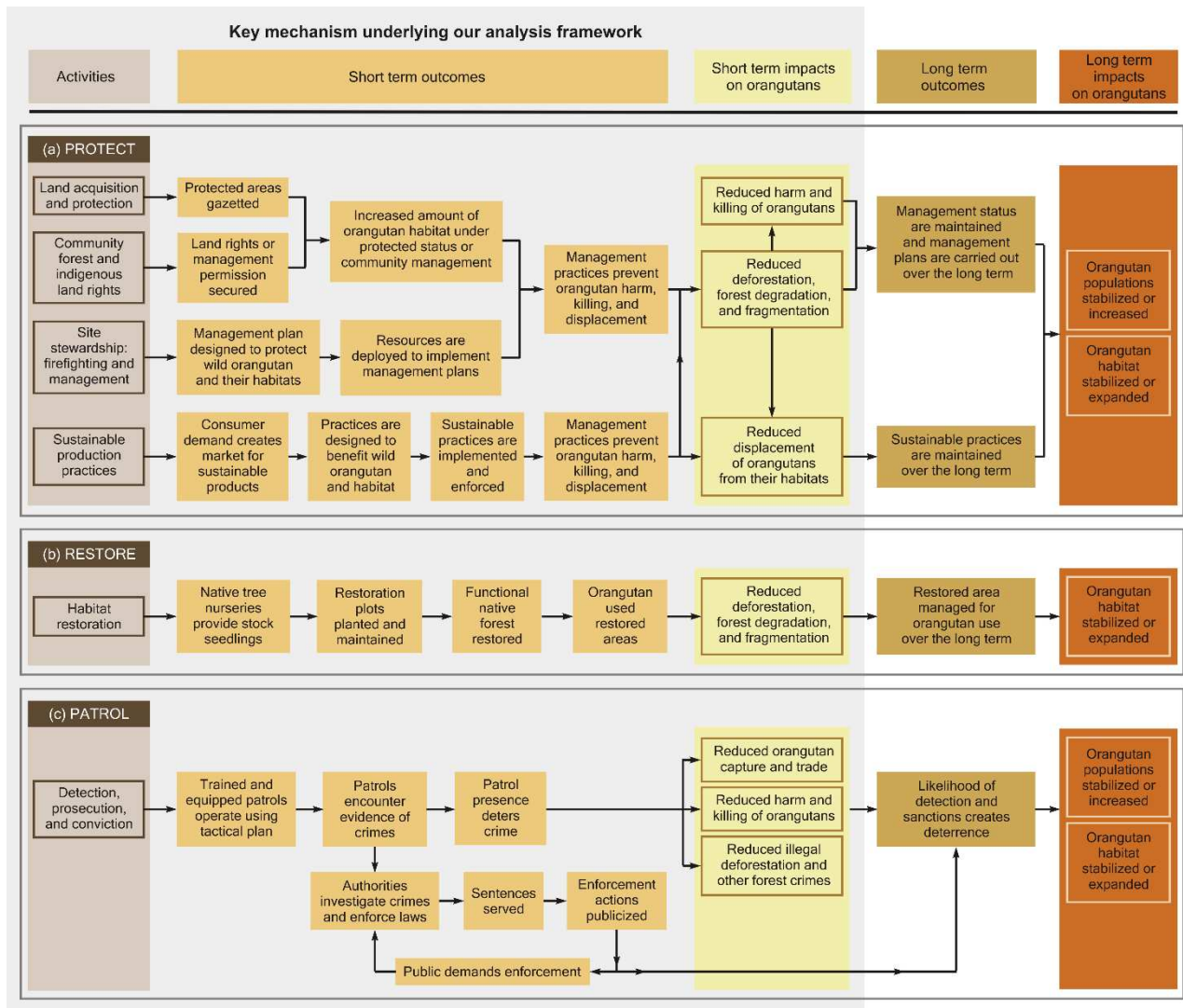
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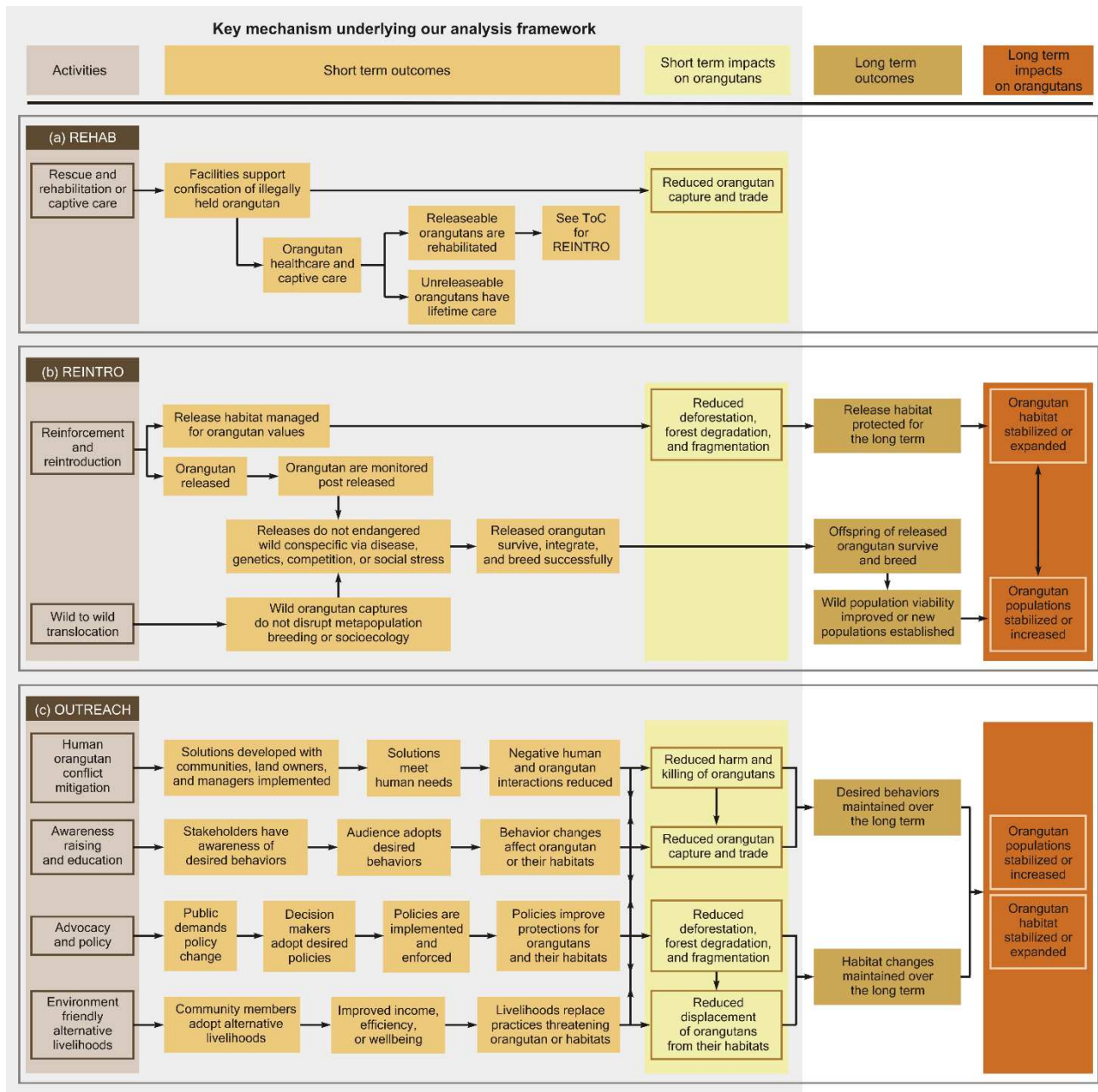


846

847 **Figure S1. Orangutan conservation Theory of Change (ToC) pathways for protection, restoration**
 848 **and patrolling. Related to STAR Methods.**

849 (a) PROTECT, (b) RESTORE, and (c) PATROL. The pathways represent the sequential outcomes possible
 850 from the conservation activity over the short term (within five years after the action is initiated) and long
 851 term (more than five years), and how these outcomes can lead to reduced threats and positive impacts for
 852 the species. Our study focuses on the short-term implications of the orangutan conservation activities (in
 853 grey background). Explanations of the ToC pathways are provided in the Data.

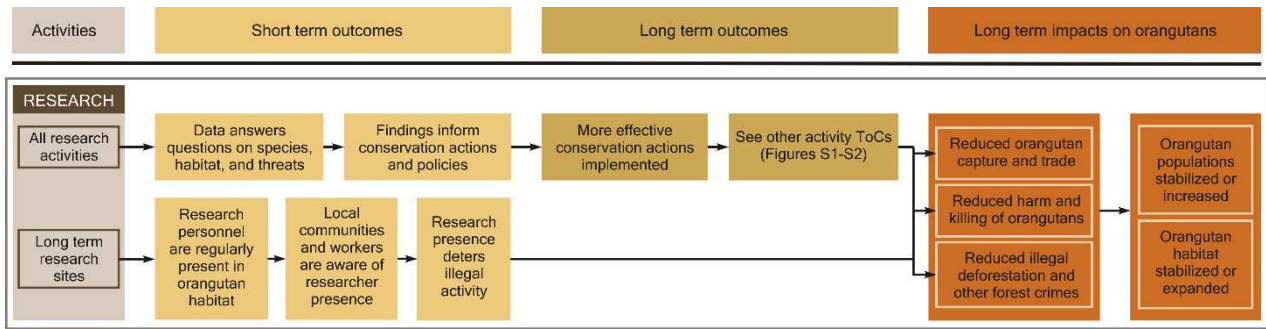
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856 **Figure S2. Orangutan conservation Theory of Change (ToC) pathways for rehabilitation,**
857 **reintroduction and outreach. Related to STAR Methods.**

858 (a) REHAB, (b) REINTRO, and (c) OUTREACH. The pathways represent the sequential outcomes
859 possible from the conservation activity over the short term (within five years after the action is initiated)
860 and long term (more than five years), and how these outcomes can lead reduced threats and positive
861 impacts for the species. Our study focuses on the short-term implication of the orangutan conservation
862 activities (in grey background). Explanations of the ToC pathways are provided in the Data.

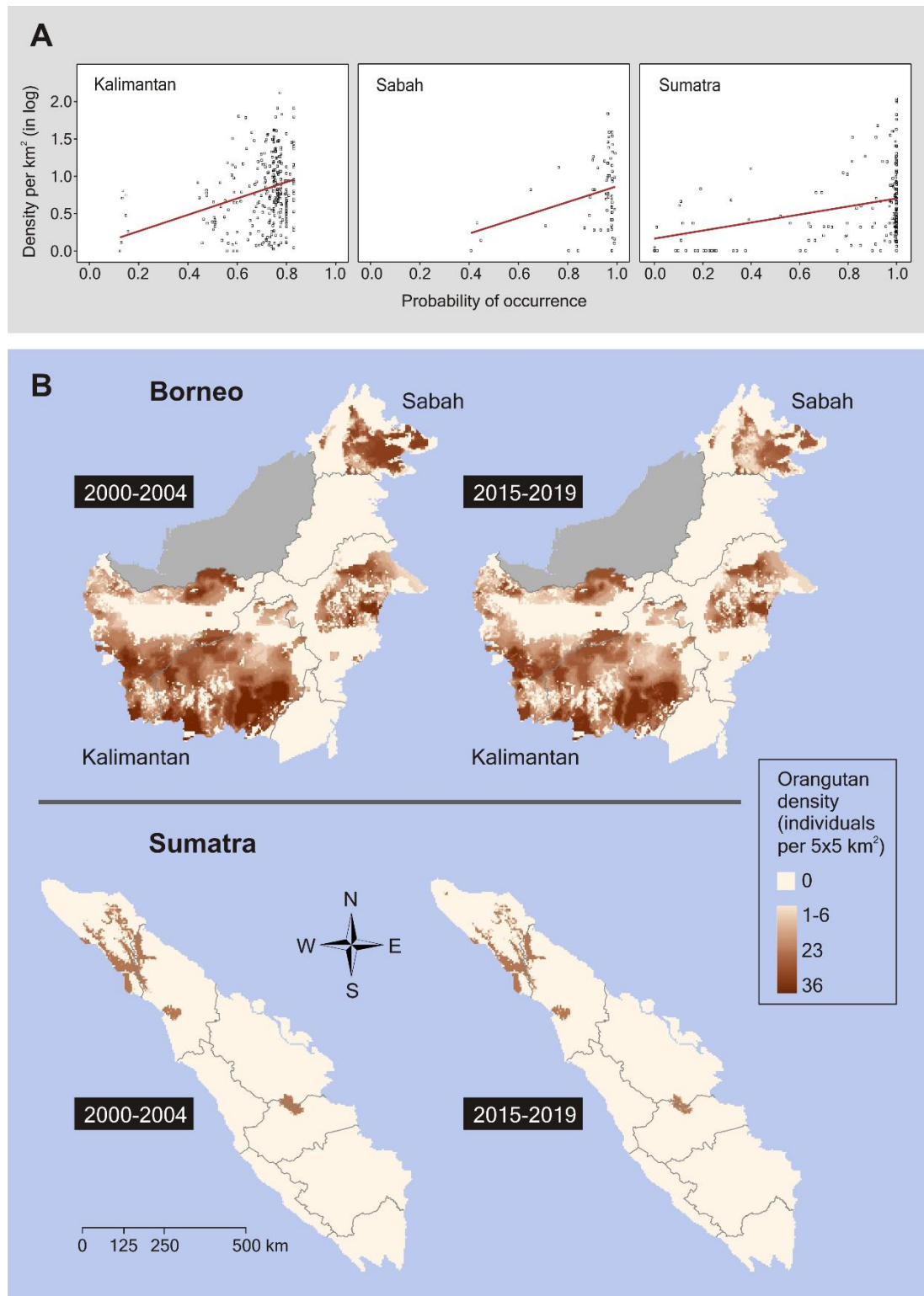
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864

865 **Figure S3. Theory of Change (ToC) pathways for orangutan related RESEARCH activity. Related to**
 866 **STAR Methods.**

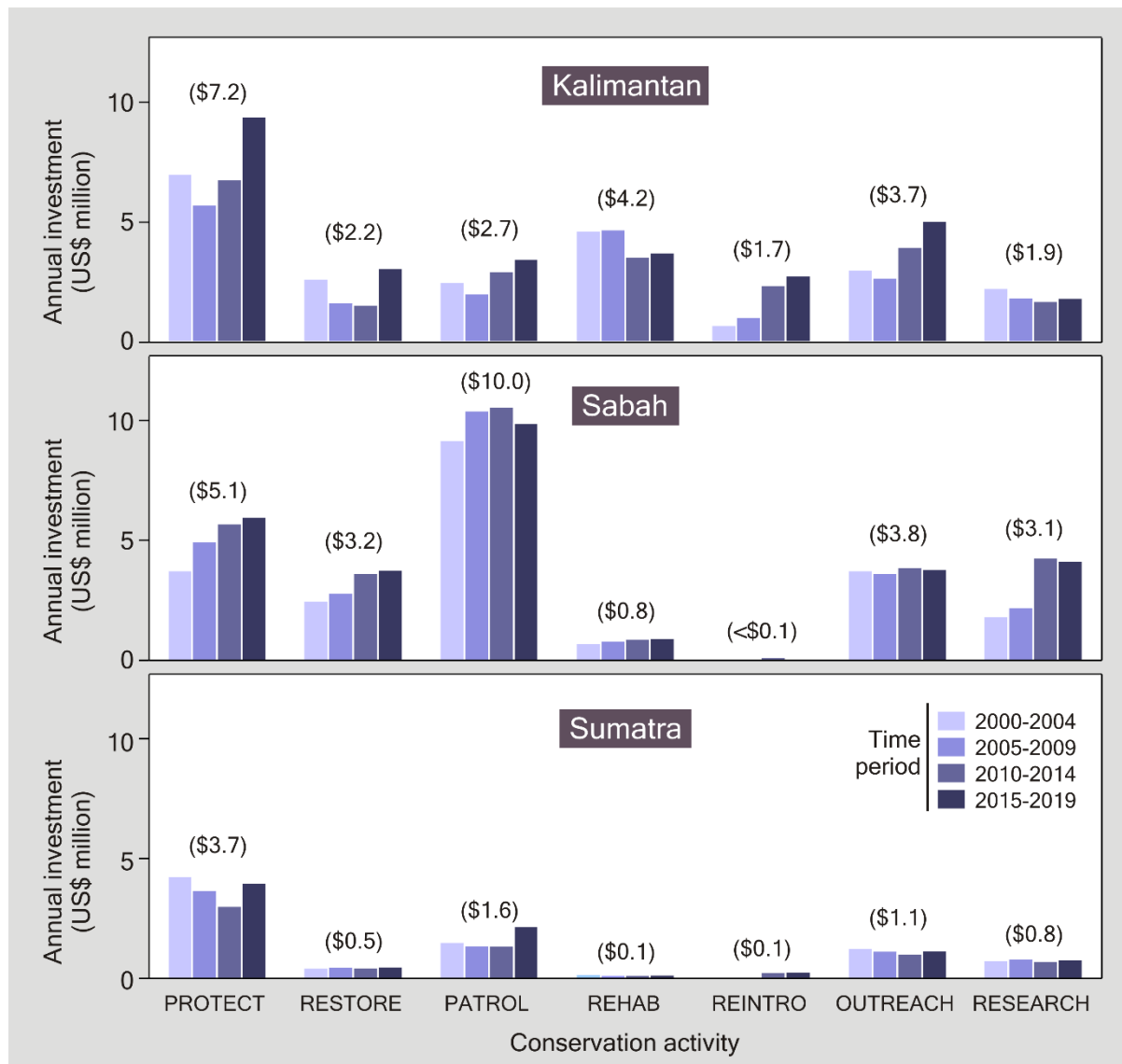
867 This represents the chain of outcomes possible from the activity within the short term (five years) and long
 868 term (beyond five years).



869

870 **Figure S4. The relationship between probability of occurrence and density and density change over**
 871 **time. Related to STAR Methods and Figure 5.**

872 (A) The relationship between the orangutan probability of occurrence and density for the three study
 873 regions. Occurrence data were generated from the Generalized Boosted Regression Models – GBM.
 874 Density was estimated from the transect dataset. (B) Estimated change in density of orangutan populations
 875 between 2000-2004 and 2015-2019. Borneo and Sumatra. Three regional-based models were used to
 876 estimate the change in orangutan distributions in (1) Kalimantan and (2) Sabah, and (3) Sumatra.



878

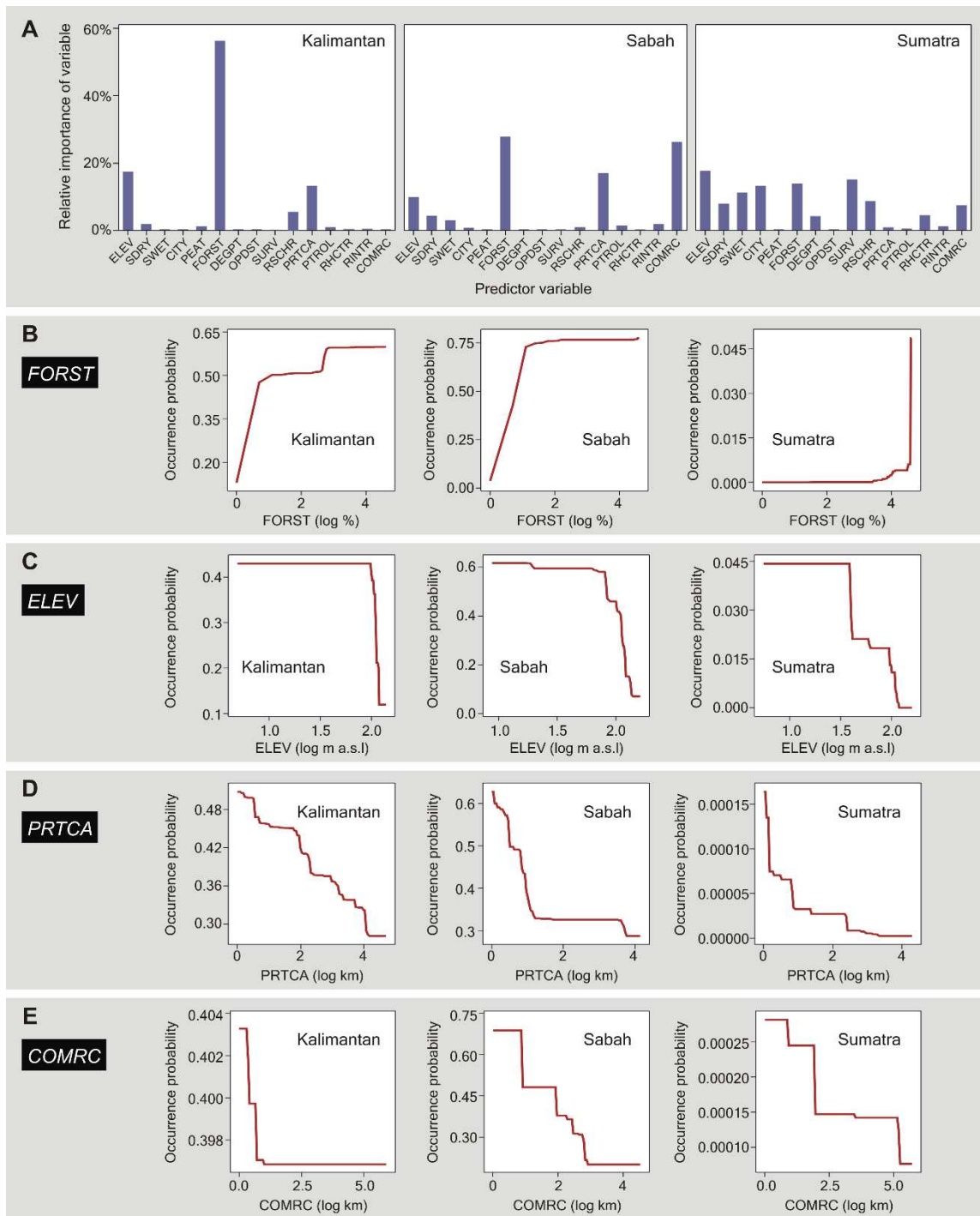
879 **Figure S5. Annual spending value on different conservation activities for the orangutan in**
 880 **Kalimantan, Sabah, and Sumatra over time. Related to Figure 4.**

881 Conservation activities assessed include the six core activities considered affecting the orangutan survival
 882 in the short term: habitat acquisition and protection (PROTECT), habitat restoration (RESTORE),
 883 patrolling and law enforcement (PATROL), rescue and rehabilitation (REHAB), translocation and
 884 reintroduction (REINTRO), and public outreach and capacity building (OUTREACH); and research-related
 885 activities considered as primarily influencing conservation actions and land use management decisions
 886 (RESEARCH). The value inside the parenthesis represents the mean annual investment value between 2000
 887 and 2019 for the associated action (in million US\$).

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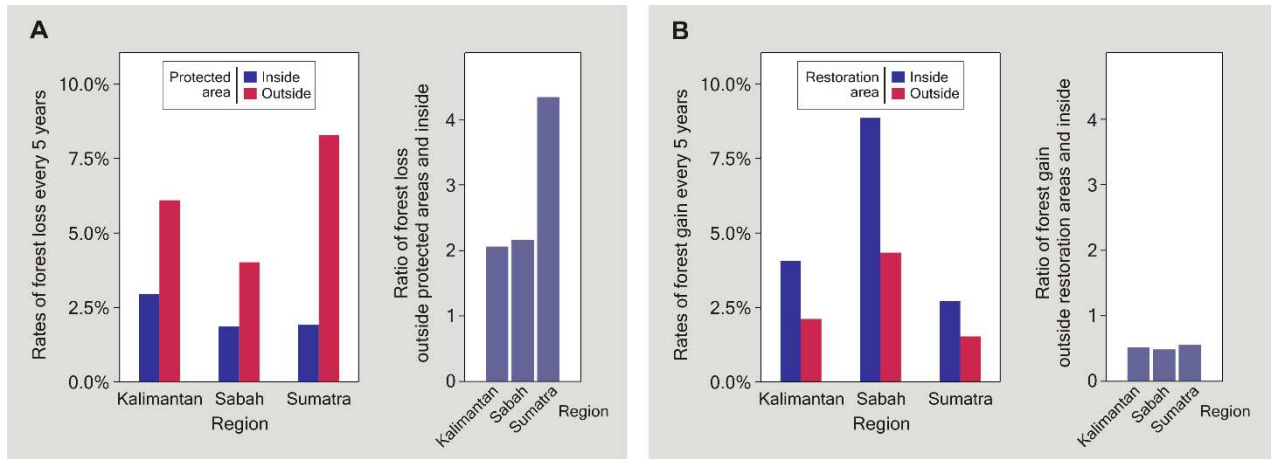
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892 **Figure S6. Predictors of orangutan occurrence. Related to STAR Methods.**

893 (A) The relative importance of environmental predictors in affecting orangutan likelihood of occurrence,
 894 and the marginal effects of predictors with high importance obtained from the three region-based GBM
 895 models for Kalimantan, Sabah, and Sumatra, including variables: (B) forest cover (*FORST*), (C) elevation
 896 (*ELEV*), (D) distance to protected areas (*PRTCA*), and (E) distance to public outreach and awareness raising
 897 programs (*COMRC*). Survey effort had a negligible effect on the likelihood of orangutan reported as
 898 presence in Kalimantan and Sabah, but in Sumatra it had a large positive association with orangutan
 899 presences (A). Forest cover and elevation are the strongest predictors of orangutan distributions in the three
 900 islands (A). The species' probability of occurrence increases with increased forest cover and reduced
 901 elevation (B-C). In Kalimantan and Sabah, proximity to protected areas has a strong positive correlation
 902 with orangutan distributions (D). In Sabah, the probability of orangutan occurrence also markedly increases
 903 with proximity to community outreach programs (E).



904

905 **Figure S7. Forest gain and loss data used in counterfactual analysis. Related to STAR Methods.**

906 Rates of (A) forest loss inside protected areas compared to the rates within a 50 km buffer zone, and (B)
 907 forest gain inside restoration sites compared to the rates within a 50 km buffer zone, every five years
 908 between 2000 and 2019 in Kalimantan, Sabah, and Sumatra.

909

910

Tables

Published and unpublished datasets	
United States Fish and Wildlife Service (USFWS) Multinational Species Conservation Fund - Great Apes grants to orangutan projects (data provided by USFWS)	
Dataset of oil palm companies operating in orangutan habitat ^{S1}	
Borneo Atlas (https://atlas.cifor.org/borneo/#en)	
Dataset of rescue centers operating in Borneo	
Websites	
<i>Site</i>	<i>Search terms</i>
United States Agency for International Development (USAID) LESTARI program (https://www.lestari-indonesia.org/en/)	
Tropical Forest Conservation Act (TFCA) Sumatra annual reports (http://tfcasumatera.org/publikasi_category/laporan-tahunan/)	
TFCA Kalimantan annual reports (https://www.tfcakalimantan.org/kanal/annual-report)	
European Union (EU) Commission funded projects by country (https://ec.europa.eu/budget/euprojects/search-projects_en)	
Critical Ecosystem Partnership Fund (https://www.cepf.net/grants/grantee-projects)	Taxon: “mammals”; Country: “Indonesia” and “Malaysia”
The Global Environmental Facility (GEF) project database (https://www.thegef.org/projects)	“Indonesia” and “Malaysia”
Mohammed bin Zayed Species Conservation Fund projects (https://www.speciesconservation.org/case-studies-projects/)	Species: “mammals”; Continent: “Asia”; Country: “Indonesia” and “Malaysia”
Darwin Initiative projects (https://www.darwininitiative.org.uk/project/)	Location; Country: “Indonesia” and “Malaysia”
Norway bilateral projects in Indonesia (https://www.norway.no/en/indonesia/values-priorities/deforestation-and-climate-change/bilateral-climate-and-forest-support/project-support/)	
Australian Agency for International Development (https://dfat.gov.au/geo/indonesia/development-assistance/Pages/development-assistance-in-indonesia.aspx)	
Japan International Cooperation Agency (https://www.jica.go.jp/indonesia/english/index.html and https://www.jica.go.jp/malaysia/english/index.html)	
Agence Française de Développement (https://www.afd.fr/en/page-region-pays/indonesia)	
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (https://www.giz.de/en/html/about_giz.html)	Worldwide: “Indonesia” and “Malaysia”
Partnerships for Forests – Our Portfolio (https://partnershipsforforests.com/what-we-do/partnerships-and-projects/)	Location: “Indonesia”
The Arcus Foundation grantees (https://www.arcusfoundation.org/grantees/)	Focus: “Great apes and gibbons”
Prince Bernhard Nature Fund (https://www.pbnf.nl/projects/)	“Indonesia” and “Malaysia”
Search engines	
<i>Site</i>	<i>Search terms</i>
Foundation Directory Online	Keywords: “orangutan”, “orang utan” and “orang-utan”

912 **Table S1. Sources used to identify additional investments in orangutan conservation. Related to Key**
 913 **Resources Table, STAR Methods.**

<p>Organizations operating across all orangutan habitats: IUCN SGA; UNEP; GRASP; Great Apes Film Initiative; Orangutan Conservancy; Yayasan Kehutanan Masyarakat Indonesia; Yayasan Swara Owa; Yayasan Ulos Heritage Indonesia (SCORPION); FORINA; CIFOR; University of Kent DICE; Borneo Futures; Wildlife Impact.</p>
<p>Organizations operating in Indonesian Kalimantan: ADB/GEF-funded project (Sustainable Forest and Biodiversity Management in Borneo); UNEP/Wetlands International Indonesia/Global Environmental Centre; Canadian Government (CIDA); UNDP – Kalimantan; Indonesian International Rural Agricultural Development Foundation; Kalimantan Prima Coal; Agro Bukit (Goodhope Holdings); Agro Wana Lestari (Goodhope Holdings); Dewata Sawit Nusantara (DSN group); Genting – Kalimantan; Globalindo Alam Perkasa (Musim Mas); Harapan Sawit Lestari; Investa Karya Bhakti; Karya Makmur Bahagia; Karya Makmur Sejahtera (Goodhope Holdings); Kridatama Lancar (Sime Darby); Mentaya Sawit Mas (Wilmar); Nabatindo Karya Utama (Bumitama); Kalimantan Agro Lestari; Rea Kaltim Plantation; Sarana Titian Permata (Wilmar); Sawit Sumber Mas Sarana; Sinar Mas – GAR; Sukajadi Sawit Mekar (Musim Mas); Swakarsa Sinar Sentosa (Sinar Mas); Tapian Nadenggan (Sinar Mas); Makin Group; Katingan Mentaya Project; Rimba Raya Restoration Ecosystem; Acacia Andalan Utama; Balayan River Timber; Bina Ovovipari Semesta; Carus Indonesia; Djima Jaya Utama; Erna Djuliawati; Graha Sentosa Permai; Gunung Gajah Abadi; Karya Lestari; Narkata Timber; Royal Lestari Utama; Saratim (Sarmiento Parakantja Timber); Sari Bumi Kusuma; Suka Jaya Makmur; Utama Damai Indah Timber; Wanasokan Hasilindo; Balai Konservasi Sumber Daya Alam Kalbar; Balai Konservasi Sumber Daya Alam Kalteng; Balai Konservasi Sumber Daya Alam Kaltim; Danau Sentarum and Betung Kerihun National Park; Gunung Palung National Park; Bukit Baka/Bukit Raya National Park; Tanjung Puting National Park; Sebangau National Park; Kutai National Park; Badan Restorasi Gambut (Peat Restoration Agency); Aidenvironment; Borneo Nature Foundation; CAN Borneo; FFI Indonesia; Friends of the National Parks Foundation; IDH Ketapang landscape; Integrated Conservation; Link-AR Borneo; People Resources and Conservation Foundation (PRCF); Planet Indonesia; Profauna; Save Our Borneo; TNC Indonesia; WALHI Indonesia; WCS Indonesia – Kalimantan; Wetlands International Indonesia; YTS/Wildlife Impact – community surveys; World Education – Indonesia; WWF Indonesia; Yayasan; Brunel University; CIMPTROP - University of Palangka; Wallacea Trust; Yayasan TITIAN; Gunung Palung Orangutan Conservation; Health in Harmony; Kutai Project; Mohammed bin Zayed Conservation Fund – in situ research funds, Kalimantan; Orangutan Land Trust; Tropenbos-International; Tuanan Orangutan Research Project/CORE Borneo; University College Birmingham – in situ research Kalimantan; BOSF Nyaru Menteng, Wanariset Samboja/Samboja Lestari, Mawas; RHO/BOSF; Center for Orangutan Protection; International Animal Rescue; Jakarta Animal Aid Network; Jejak Puleng; Orangutan Foundation UK; Orangutan Foundation International; Sintang Orangutan Centre; Tenggara rescue/transfer facility.</p>
<p>Organizations operating in Malaysian Sabah: Anika Desiran; Deramakot Forest Reserve; INIKEA; Mayvin Grouping; PONGO Alliance; Sapulut; TSH Resources - natural forest management; TSH Resources -oil palm; Yayasan Sabah; Linbar 1 and 2 Estates; Litang Estate; Santosa Estate (Sime); Sg. Pin Estate; Sungai Segama II; Tabin Estate; Tagas Estate; Sabah Softwoods; Tungku Estate (Sime); Wilmar - Sabah Mas estate (Tabin) (excluding PONGO Alliance); Genting; Sabah Environmental Protection; Sabah Forestry Department; Sabah Parks; UE - REDD+; UNDP; Borneo Conservation Trust – Japan; Borneo Conservation Trust – Sabah; Ecohealth Alliance; Friends of the Orangutan (FOTO); HUTAN-KOCP; HUTAN - via Wildlife Connection; LEAP; Malaysia Palm Oil Wildlife Conservation Fund; Orangutan Appeal-UK (Sabah); Orangutan Appeal-UK (Sabah Wildlife Rescue Unit); Rhino and Forest Fund; PACOS; Rainforest Trust/SEARRP; Sabah Environmental Protection Association; WWF-Sabah; WWF-Sabah Living Landscapes; Danau Girang Field Center; Durrell Trust for Conservation; Liverpool John Moores University; Living Landscape Alliance; Orangutan Appeal-UK (Sabah _ tabin PRM project); SEARRP - SAFE Project; Yayasan Sime Darby; Sepilok.</p>
<p>Organizations operating in Indonesian Sumatra: UNDP; TFCA/Leuser Conservation Partnership; Asia Pacific Resources International Limited (APRIL); Royal Lestari Utama; North Sumatra Hydroelectric Company; Balai Konservasi Sumber Daya Alam Sumatera Utara; Balai Konservasi Sumber Daya Alam Sumatera Jambi; Gunung Leuser National Park; Bukit Tigapuluh National Park; Conservation International Indonesia; FKL; Frankfurt Zoological Society; HAKA; INDECON; Institute Green Aceh (IGA); Jantho Lestari Consortium; Lembaga Suar Galang Keadilan; Leuser Ecosystem Management Authority Employee Forum; Nature for Change; Orangutan Information Center; Orang Utan Republik/TOP; PADHI Foundation; Penyangga Tengah Kawasan Ekosistem Leuser; PETRA; Rainforest Action Network; Rainforest trust/KEHUS; Sumatra Ranger Project/Yayasan Cahaya Anak Nusantara; Sumatran Rainforest Institute/tapanuli Orangutan Conservation Project (TOCOP); Universitas Nasional (Unas) Faculty of Biology; WALHI Indonesia; WCS Indonesia – Sumatra; Wetlands International Indonesia; Yayasan Konservasi Satwa Liar Indonesia (YKSLI); Yayasan Leuser International (Leuser International Foundation, YLI); Yayasan Ulos Heritage Indonesia (SCORPION); Ketambe; FORINA (Sumatra); Soraya; Jakarta Animal Aid Network; SOCP; SKEPHI (Sekretariat Kerjasama untuk Pelestarian Hutan Indonesia; WildAid – Leuser project; Yayasan EKONA; Yayasan Perlindungan Lingkungan Hidup dan Pelestarian Alam (Yayasan Palapa); Leuser Development Project.</p>

916 **Table S2. List of entities included in orangutan conservation investment dataset. Related to Key**
917 **Resources Table, STAR Methods.**

918 The analysis includes publicly available financial data for organizations whose names have been excluded
919 for confidentiality reasons.

Variable	Variable abbreviation	Static/Dynamic	Data sources
Elevation (m a.s.l)	<i>ELEV</i>	Static	SRTM 90m Digital Elevation Database v4.1 ^{S2}
Rainfall during the dry season (mm)	<i>SDRY</i>	Static	WorldClim ^{S3}
Rainfall during the wet season (mm)	<i>SWET</i>	Static	WorldClim ^{S3}
Distance to nearest city (km)	<i>CITY</i>	Static	Provincial map from the Geospatial Information Agency Indonesia S4 and GeoNames Gazetteer ^{S5}
Percentage of peatland area	<i>PEAT</i>	Static	Peat hydrological area map ^{S6}
Percent forest cover	<i>FOREST</i>	Dynamic	Global Forest Change dataset ^{S7} , Indonesia's primary and secondary forest map ^{S8} , and Intact Forest Landscapes data ^{S9}
Percentage of degraded peatland	<i>DEGPT</i>	Dynamic	Peat hydrological area map ^{S6} , Global Forest Change dataset ^{S7} , Indonesia's primary and secondary forest map ^{S8} , and Intact Forest Landscapes data ^{S9}
Distance to oil palm plantations (km)	<i>OPDST</i>	Dynamic	Oil palm plantation distribution map ^{S10-13}
Survey effort	<i>SURV</i>	Dynamic	Orangutan survey datasets across Indonesia and Malaysia ^{S14-18}
Distance to research centres/activities (km)	<i>RSCHR</i>	Dynamic	See Table 1
Distance to protected areas (km)	<i>PRTCA</i>	Dynamic	Forest Zone Maps ^{S14,19} , Community Forestry areas ^{S20}
Distance to patrolling activities (km)	<i>PTROL</i>	Dynamic	See Table 1
Distance to rehabilitation centres (km)	<i>RHCTR</i>	Dynamic	See Table 1
Distance to reintroduction sites (km)	<i>RINTR</i>	Dynamic	See Table 1
Distance to public outreach programs (km)	<i>COMRC</i>	Dynamic	See Table 1

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921 **Table S3. Environmental predictors used in the Generalized Boosted Regression Models (GBM) to**
922 **generate the estimated change in orangutan distributions. Related to Key Resources Table, STAR**
923 **Methods.**

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