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1 **Top 100 research questions for biodiversity conservation in Southeast Asia**

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71 **Top 100 research questions for biodiversity conservation in Southeast Asia**

72 **Abstract**

73 Southeast (SE) Asia holds high regional biodiversity and endemism levels but is also one of the
74 world's most threatened regions. Local, regional and global threats could have severe consequences
75 for the future survival of many species and the provision of ecosystem services.

76 In the face of myriad pressing environmental problems, we carried out a research prioritisation
77 exercise involving 64 experts whose research relates to conservation biology and sustainability in SE
78 Asia. Experts proposed the most pressing research questions which, if answered, would advance the
79 goals of biodiversity conservation and sustainable development in SE Asia. We received a total of
80 333 questions through three rounds of elicitation, ranked them (by votes) following a workshop and
81 grouped them into themes.

82 The top 100 questions depict SE Asia as a region where strong pressures on biodiversity interact in
83 complex and poorly understood ways. They point to a lack of information about multiple facets of
84 the environment, while exposing the many threats to biodiversity and human wellbeing. The themes
85 that emerged indicate the need to evaluate specific drivers of biodiversity loss (wildlife harvesting,
86 agricultural expansion, climate change, infrastructure development, pollution) and even to identify
87 which species and habitats are most at risk. They also suggest the need to study the effectiveness of
88 practice-based solutions (protected areas, ecological restoration), the human dimension (social
89 interventions, organisational systems and processes and, the impacts of biodiversity loss and
90 conservation interventions on people). Finally, they highlight gaps in fundamental knowledge of
91 ecosystem function. These 100 questions should help prioritise and coordinate research,
92 conservation, education and outreach activities and the distribution of scarce conservation
93 resources in SE Asia.

94 **Key words:** conservation biology, expert elicitation, extinction, research priorities, sustainability.

95 **INTRODUCTION**

96 When it comes to bridging the gap between researchers and decision-makers, there is growing
97 recognition of the value of collaborative exercises (research-priority setting and horizon scanning)
98 that support conservation priorities (Kark et al. 2016; Sutherland et al. 2011). So far, such
99 endeavours have focused on questions of: global importance (e.g., Sutherland et al. 2009), regional
100 importance (e.g., Weeks and Adams 2017), national importance (e.g., Morton et al. 2009; Prescott et
101 al. 2017; Rudd et al. 2010); or of relevance to specific ecosystems (e.g., Parsons et al. 2014), taxa
102 (e.g., Hamann et al. 2010) or conservation threats (e.g., Morris et al. 2016; Pretty et al. 2010). Yet
103 tropical regions, despite having the greatest levels of biodiversity and threat globally (Barlow et al.
104 2018), have rarely been the explicit focus of research-priority setting and horizon scanning exercises.

105 Such exercises seem especially valuable in SE Asia, a region whose biodiversity and rate of species
106 discovery are very high (Hughes 2017a) but where conservation threats are pervasive and severe
107 (Sodhi et al. 2010b). Causes include rapid land-use and land-cover change concomitant with some of
108 the world's fastest regional population growth, economic development, industrialization (Hirsch
109 2016) and urbanization (Schneider et al. 2015) and unsustainable natural resource management
110 (Wilcove et al. 2013).

111 Determining how to strike a balance between development and conservation is especially complex
112 in Southeast (SE) Asia. One reason is that the region (i.e., the 10 member-states in the Association of
113 Southeast Asian, or ASEAN), epitomises income inequality, both within and among nations. The
114 development gap between two of the world's wealthiest countries (Singapore and Brunei) and the
115 other eight is especially vast (see also Carpenter et al. 2013). This creates large disparities in: the
116 capacity to fund conservation research and implement projects, levels of consumption and concern
117 for the environment (e.g., Mills Busa 2012). Another reason is that even though ASEAN membership
118 dictates that all ten national governments cooperate on environmental issues, vast differences in
119 culture, governance, corruption and the rule of law accentuate already challenging transboundary
120 issues (many of which also involve countries outside the region; see also Hirsch 2016). This is
121 exemplified by the issue of hydropower development, which is proceeding apace in SE Asia (Zarfl et
122 al. 2015). In the Mekong, existing and planned dams (especially on the upper reaches in China) stand
123 to massively transform one of the world's most biodiverse and productive river basins, displace
124 millions of SE Asians and eliminate many of the river's ecosystem services (Gibson et al. 2017 and
125 others cited therein).

126 In this context, we set out to develop a list of the top research questions which, if answered, would
127 substantially advance the goals of biodiversity conservation and sustainable development in SE Asia.
128 The ultimately objective of this regional research-priority setting exercise is to identify common
129 priorities for research and suggest how to make said research practical and policy-relevant.

130 **METHODS**

131 The first and last authors systematically selected potential contributors, as follows. First, we
132 reviewed the list of delegates at the 2016 Joint Meeting of the Society for Conservation Biology (Asia
133 Section) and Association for Tropical Biology and Conservation (Asia-Pacific Chapter), held in
134 Singapore (<https://www.conservationasia2016.org/>). We identified all PhD holders who were
135 actively doing conservation research in the region. We augmented this list by a Google Scholar
136 Search, using the search terms “conservation” AND “Southeast Asia”, “sustainability AND “Southeast
137 Asia” and “biodiversity” AND “Southeast Asia”. We looked for authors who were currently active,
138 well-cited and from a range of disciplines including conservation biology, agroforestry, climate
139 change, conservation genetics, systematics, disaster-risk reduction, ecology, energy policy,
140 conservation policy and advocacy, social sciences, marine protected areas, ocean acidification and
141 hypoxia. Finally, we tapped into our networks, i.e., contacts working for government and NGOs and
142 colleagues who conduct research in these areas.

143 We generated a list of 114 potential contributors and invited them to participate via email.
144 Participation entailed submitting research questions that addressed this overarching one: “What
145 research question, if answered, would substantially advance the goals of sustainable development
146 and biodiversity conservation in SE Asia?” We encouraged participants to tap into their own
147 networks to gather questions. We solicited questions (via a Google form or email) that met the same
148 eight criteria stipulated by Sutherland et al. (2009). The questions had to: (1) be answerable through
149 a realistic research design, (2) be answerable on the basis of facts rather than value judgments, (3)
150 address important gaps in knowledge, (4) not be formulated as a general topic area, (5) be of a
151 spatial and temporal scale that could be addressed realistically by a research team or program, (6)
152 not just be answerable with a response of ‘yes’, ‘no’, or ‘it depends’, (7) if related to impact and
153 interventions, contain a subject, an intervention and a measurable outcome (and thus, immediately
154 suggest a research design needed to address the question), (8) increase the effectiveness of policy
155 about, and management of, resource use and biodiversity in the face of environmental stressors.

156 We received a total of 218 questions from 64 individuals, who reported that 364 individuals were
157 involved in generating them. The 52 co-authors of this paper further contributed by reviewing the
158 questions and voting on them, assigning each a score of 5 (top priority), 2 (medium priority) or 0
159 (low priority) – a system we devised to give more weight to top-priority questions. To make this
160 exercise more practical and policy-relevant, we also asked them to: (1) offer suggestions on how to
161 answer specific questions or key datasets/models that could help answer multiple questions, and (2)
162 identify institutional, decision-making actors and processes that would need to be engaged to
163 implement research projects and outputs. Finally, we sought qualitative feedback on questions (e.g.,
164 proposing themes, highlighting redundancies, rephrasing) and invited them to suggest any new
165 questions they felt were missing from the original set. We received 77 new questions, which
166 contributors then voted on in a second round, using the same system.

167 We held a two-day workshop (20 to 21, November 2017) in Singapore and 31 contributors attended.
168 At the workshop, we discussed questions identified as problematic in the first two rounds of voting
169 and asked attendees to propose questions that they still felt were missing. This produced 38 new
170 (third-round) questions, and thus a total pool of 333 potential questions. We divided attendees into
171 breakout sessions based on fields and countries of expertise to address the aspects of practicality

172 (how to answer specific questions) and policy relevance (which actors and processes to engage).
173 L.R.C. provided suggestions on how to answer the third-round questions and those not answered
174 during the workshop. Finally, the 53 co-authors voted on the 38 third-round questions (after the
175 workshop).

176 The first and last authors ranked questions by average scores, edited them for readability and
177 merged ones we deemed similar. More specifically, we determined that 39 questions in the initial
178 top 100 appeared to overlap substantially with others, denoting that multiple experts agreed on
179 their importance when proposing them. We merged them into 13 questions, and then promoted the
180 next most highly-ranked questions in the list to the top 100. We also deleted one question because
181 we decided *post-hoc* that it did not meet criterion 1.

182 We also categorized the top 100 questions in two ways to facilitate comparisons with prior and
183 future exercises. First, we classified them by approach (as in Kark et al. 2016): descriptive questions
184 describe a problem/threat; proactive ones refer to interventions (we classified some as both). Next,
185 we assigned them to biome-relevant categories depending on whether they dealt specifically with
186 freshwater, marine or terrestrial issues or were not biome-specific (some questions fell into more
187 than one category). The last author scored relationships between each of the top 100 questions and
188 each of the Sustainable Development Goals (SDGs).

189 **RESULTS**

190 We present the top 100 questions in Table 1, organised into 13 themes (although many could fall
191 into more than one theme and other groupings are possible). Although we used 100 as a cut-off for
192 convenience, natural cut-offs occurred at the ~50th and ~250th questions (Fig. S1), and differences in
193 average scores between consecutively-ranked questions are small. Thus, many questions that did
194 not make the top 100 are not much lower in priority than those that did. Therefore, we present the
195 total pool of questions with their: original ranks, themes, approaches and biome-relevant categories
196 (Table S1) along with each theme's retention rate, i.e., proportion of questions voted into the top
197 100 (Fig. S2). Retention rates varied from 21.9 to 72.7 %.

198 Our top 100 list includes nearly even numbers of descriptive (55) and proactive (53) questions – the
199 total pool is slightly more biased toward descriptive questions (57 %; Table S1). Most questions are
200 not biome-specific (59 in the top 100; 56 % of the total pool), but of those that are, most refer to the
201 terrestrial realm (71 and 76 %, of the top 100 and total pool, respectively). Marine-related questions
202 represent 22 and 13 %, and freshwater-related questions make up 15 and 11 % of biome-specific
203 questions in the top 100 and total pool, respectively.

204 The most common practical approaches to answering the top 100 questions (Table S2) involve
205 experimentation (e.g., control-impact / before-after) – mentioned as key to addressing 33 questions.
206 The next most commonly suggested approaches are (in decreasing order): mathematical modeling
207 (including Bayesian inference), field surveys, mapping, anthropological / psychology methods and
208 the use of existing data. Methodologies mentioned less often include meta-analysis, systematic-
209 conservation-planning tools, telemetry, artificial intelligence, market research, valuation, case
210 studies, molecular techniques, supply-chain-analysis, network analysis, longitudinal studies and
211 matching analysis.

212 When it comes to policy relevance (i.e., which agencies and stakeholders to engage in each country;
213 SI-1), our exercise identifies a range of actors typically associated with national forestry and
214 agriculture departments. It also clearly highlights the need to (1) align research with national
215 priorities, (2) understand agencies' key performance indicators and (3) invest time in building
216 relationships with policymakers. Bridging the research-implementation gap also involves engaging
217 local universities and NGOs. Thus, our exercise points to the value of multi-pronged approaches
218 engaging multiple stakeholders at multiple levels.

219 The exercise of mapping our questions to the SDGs (Table S3) reveals how strongly our list
220 emphasises terrestrial biodiversity, with 81 of the top 100 linked to SDG 15 (life on land). Also well-
221 represented are SDG 14 (life below water; 49 questions), SDG 2 (zero hunger; 48 questions) and SDG
222 1 (no poverty; 46 questions). However, most questions highlight trade-offs between conservation
223 and development and conflicts among the SDGs themselves. For example, a common trade-off was
224 between SDGs 1, 2 and 8 (decent work & economic growth) and SDGs 14 and 15.

225 **Table 1**

226 One hundred priority research questions for biodiversity conservation in SE Asia. Questions are
 227 organised into 13 themes (italicised) and should be regarded as independent units – their order does
 228 not reflect final ranking, but themes are ordered by respective numbers of questions. Merged
 229 questions are in bold.

<i>PROTECTED AREAS (PAs) – PRACTICE-BASED INTERVENTION</i>	
1.	How well are PAs actually protected, and what actions are needed to enhance protection?
2.	What are the factors that determine the effectiveness of PA management?
3.	How effective is enforcement in PAs?
4.	To what extent have existing PAs been degraded by human activities (e.g., encroachment, illegal exploitation, poaching)?
5.	How much of various biodiversity components (e.g., endangered species, phylogenetic and functional diversity, richness, evenness, divergence) do terrestrial and marine PAs in SE Asia currently protect?
6.	How much is invertebrate biodiversity reflected in that of plants and vertebrates? For example, are PAs (often based on mammals) adequately protecting invertebrates?
7.	How should new PAs be selected to maximise the resilience of ecosystems and natural resources?
8.	What longer-term research on food webs and fragmented biodiversity is needed to determine necessary size and shapes of reserves that will stand the test of time?
9.	How sufficiently are data on spawning, nursery and aggregation of fisheries resources considered in planning and zoning of marine PAs (MPAs) in SE Asian seas?
10.	What proportion of species will likely disappear from PAs (i.e., not have viable populations in a given time period) if remaining habitat outside PAs is lost?
11.	What is the potential for PAs (as currently managed) to sustainably generate income for local communities?
12.	How do formal PAs compare with privately-managed lands (by community conservancies, NGOs dedicated to managing land for conservation) in terms of biodiversity conservation value, ES and the range and intensity of threats?
13.	Given increasing regional demand for cement, which karst habitats should be protected, and how should they be managed within a landscape matrix (i.e., how much forest buffer is needed to maintain microclimate)?
14.	What are the most effective approaches to protecting wide-ranging species beyond the boundaries of PAs?
15.	What are the key areas to protect when considering multiple species, the human dimension (e.g., corruption) and future predictions (e.g., climate change)?
<i>WILDLIFE HARVESTING – DRIVER</i>	
16.	Where are the wildlife poaching hotspots, and which species are being hunted in them?
17.	How much marine wildlife is landed daily throughout SE Asia, and how much of it is consumed locally, traded nationally and internationally?
18.	What are the regional conservation statuses and sustainable takes of economically-important fishes (e.g., food, live fish trade)?
19.	What are the impacts of international trade on fisheries and marine biodiversity of SE Asian countries?
20.	How do social norms (at local and national scales) affect poaching pressure in PAs?

21. **What is the combined impact of wildlife harvesting practices (trapping and hunting) and habitat loss on SE Asia's biodiversity? Would this impact be reversible in future provided deforestation slows down?**
22. What social science methods and approaches are most effective for researching and obtaining reliable data on the scale and patterns of the illegal wildlife trade (IWT)?
23. **How can we most effectively identify suppliers, markets and weaknesses in the enforcement of legal systems for the IWT?**
24. What is the extent of the online trade in illegal wildlife involving SE Asian flora and fauna, and how can we curb it?
25. How can we map and quantify, in real-time, the trade in imperiled wildlife within and between SE Asian nations and that leaves SE Asia, thus allowing us to intervene in a timely manner?
26. What legal (enacted and enforced existing regulations and agreements, e.g., CITES) and social interventions would most effectively minimise the online and offline IWT?
27. **What strategies might effectively reduce the demand for and trade in wild animals and animal parts (e.g., for IWT products used in traditional Chinese medicine by high- and middle-class consumers)?**
28. How long do deterrent effects of conservation interventions (counter-wildlife trafficking, anti-poaching, community outreach) last after cessation, and what factors promote their longevity?

AGRICULTURAL EXPANSION – DRIVER

29. Which agricultural commodities are driving degradation/deforestation in intact forest landscapes (especially outside PAs), and how will shifting agricultural trends and government priorities (e.g., food security targets, export targets) impact future forest conversion trends?
30. Given different scenarios of projected demand for agricultural expansion in SE Asia, where should we best place new agricultural land to minimise impacts on biodiversity?
31. Where is forest loss in SE Asia and where is it due to replacement by tree crops?
32. Which best practices would make oil palm plantations more “biodiversity-friendly”?
33. **How successfully are certification schemes (e.g., RSPO, Rainforest Alliance) preventing deforestation/plantation expansion and meeting environmental/social standards?**
34. What economic costs and benefits do agricultural and logging companies accrue when they introduce sustainability measures in their supply chains?
35. Would identifying new, high-yield varieties of oil palm, eucalyptus and rubber help spare land for nature or perpetuate deforestation in the region?
36. What factors influence whether increased land tenure security for smallholder farmers increases or decreases the probability of deforestation?
37. What are the differences between lands held by corporations and smallholders in terms of soil health & above-ground biodiversity under agricultural cover?
38. What are the impacts of expanding rubber plantations on stream water quality, aquatic biodiversity and human livelihoods?
39. What has been the impact of forest / peatland fires on conservation objectives and priorities in affected SE Asian countries?

ECOSYSTEM SERVICES (ES) & HUMAN WELLBEING

40. What are the values of key ES in SE Asia?
41. Which changes to biodiversity pose the greatest risk to essential ES?

42. How does landscape structure affect ES and functional diversity?
43. **How do habitat degradation and declining biodiversity alter the prevalence of diseases (communicable and non-communicable)?**
44. Are global threats identified for bees and other pollinators demonstrable in SE Asia and, if so, are the drivers the same?
45. How can the benefits of (eco)tourism be maximised while minimising adverse impacts on terrestrial and marine ecosystems?
46. What livelihood support programs would most effectively raise the level of support for forest conservation among marginalized, forest-dependent people?
47. What is the economic benefit-cost ratio of preserving remaining catchment forests in flood-prone areas of SE Asia?
48. What are the key factors underlying win-win outcomes for biodiversity and poverty alleviation in biodiversity hotspots?
49. What are the factors that determine the equitability of the outcomes of a conservation intervention?

DOCUMENTING BIODIVERSITY LOSS & DRIVERS

50. Can we quantify (e.g., taxonomically, geographically) the biggest threats to biodiversity, as well as how they vary in space and time?
51. What is the rate of extirpations of coastal species within each country?
52. What endemic species are at risk in karst habitats? How are these habitats and species distributed, and where are the current threats due to mining for limestone?
53. Are areas of endemism and microhabitats that serve as reservoirs of threatened biodiversity for under-researched taxa (e.g., insects, fungi) being overlooked due to gaps in data and traditional focus on megafauna and flora?
54. Where are the priority regions in SE Asia to save island and mainland endemics from extinction, and what are the most resource-effective ways to do so?
55. Which areas in SE Asia will see an increase, decrease or no change in the human footprint over the next 10-20 years?
56. What trade flows entail the highest risk of invasive species and associated diseases entering and establishing in SE Asia?
57. What are the political, social and economic drivers of ecosystem degradation? What approaches would be practical and effective to reduce this threat to biological integrity?
58. What are the main drivers of deforestation within Key Biodiversity Areas (KBAs) in SE Asia?

CLIMATE CHANGE – DRIVER

59. **What are species' responses to climate change (i.e., shifting distribution, population increase/decrease) in SE Asia?**
60. What species (e.g., endemic, economically important, keystone) and ecosystems are most likely to be adversely affected by climate change, and why?
61. How can we quantify the impacts of climate change on coastal ecosystems in this region?
62. How do we identify and prioritise which species / communities should be the focus of investment in climate change adaptation?
63. What will be the synergies, interactions and cumulative impacts of existing stressors and climate change on natural ecosystems, and the implications of those for managing ecosystems and natural resources?
64. Is the dispersal / range shift of species in response to climate change restricted by habitat availability and / or anthropogenic barriers?

65. Are protected area (PA) networks in SE Asian countries ready to address species' range shifts due to climate change?
66. How will climate change affect major cash crops in the region?

RESTORATION – PRACTICE-BASED INTERVENTION

67. **Where and when is ecological restoration a cost-effective conservation strategy in SE Asia? And which restoration areas would yield the best biodiversity outcomes regardless of cost?**
68. What factors can be manipulated to accelerate forest succession in degraded tropical peat swamps and restore their hydrological and carbon sequestration functions?
69. Where are hotspots of idle / degraded land in SE Asia that could be reforested, and what is the economic benefit-cost ratio of doing so?
70. How does the biodiversity value of logged tropical forests increase, remain unchanged or decline over time?
71. What are the best management strategies (e.g., removing or retaining old palms, enrichment planting) for restoring riparian areas in plantation / human-modified landscapes?
72. How successful are ecological restoration projects that target coastal systems, and how do we define 'success'?

ECOSYSTEM FUNCTION

73. **What are the ecological consequences of the widespread loss of large herbivores (e.g., rhinos, elephants, orangutans) and top predators in SE Asian ecosystems?**
74. **How much future connectivity (e.g., as corridors) is needed to maintain current levels of biodiversity in SE Asia's increasingly fragmented landscapes? And how do habitat requirements in corridors vary among species?**
75. What freshwater species (e.g., endemic, keystone) and ecosystem functions are most likely to be adversely affected by contemporary management?
76. How much forest cover is needed to maintain a healthy gene pool of the top predators / narrowly endemic species in each habitat?
77. What are the trophic effects of the fisheries decline in the South China Sea?

INFRASTRUCTURE – DRIVER

78. **Of the infrastructure projects (e.g., roads, dams, railroads, mines, energy projects) imminently planned for SE Asia, which ones are most damaging in terms of overall impacts on biodiversity and ES?**
79. Which priority biodiversity areas and species will be affected by planned hydropower dams in SE Asia?
80. What are the impacts of regional infrastructure development (e.g., coastal reclamation, dams, roads, powerlines/grids, shipping lanes) on migratory species (e.g., populations, movement routes/corridors, feeding and breeding grounds), and what priority interventions are needed to mitigate these impacts in terrestrial and marine biomes?
81. Are wind turbines causing mortality of birds and/or bats in SE Asia and, if so, is it large enough to warrant mitigation strategies? If large, which mitigation strategies would be most cost-effective?
82. To what extent and how quickly has coastal development changed ecological connectivity of marine organisms (e.g., ability to disperse and settle)?

SOCIAL INTERVENTIONS

83. Which interventions would effectively change peoples' minds about conservation in SE Asia?

84. How effective have various interventions (e.g., media campaigns, outreach, disincentives, policy instruments) been in reducing demand for wildlife products in the region while considering cultural factors and socioeconomic status of the target audience?
85. Which intervention campaigns targeted at promoting pro-environmental attitudes and reducing consumer demand (e.g., wildlife trade, plastic pollution and high carbon-footprint products) by urbanites have succeeded and why?
86. What are the preferences of youth when it comes to conservation (e.g., strategies that can get them to care about it, impacts of their declining involvement in agriculture)?

TRADE-OFFS BETWEEN DEVELOPMENT & CONSERVATION

87. What are the socioeconomic opportunity costs of biodiversity conservation in SE Asia?
88. How can we mobilise support from local communities for large-scale conservation?
89. How much forest (in extent and proportion of total land area) in each SE Asian nation could be preserved while allowing the rest to be converted and developed to contribute to national development targets (e.g., regional GDP, per capita income above the poverty line)?
90. How should urban development proceed so that its impacts on biodiversity are minimised?
91. What are the current extent and biodiversity value of natural or semi-natural areas (e.g., selectively-logged forests) outside formal PAs, and what policy drivers and approaches would encourage retention (i.e., discourage conversion to other land uses)?

ORGANISATIONAL SYSTEMS & PROCESSES

92. How can we improve the transfer of knowledge from academics to decision-makers bearing in mind the cultural context of SE Asia?
93. What kinds of landscape planning tools do decision-makers in SE Asian countries want, and how would such tools impact planning decisions?
94. **How do we plan for the transboundary conservation of highly mobile taxa to ensure there is adequate habitat remaining in their natural range?**
95. How do government policies and consumer demand in some countries affect agricultural development and resource extraction – and associated environmental impacts – in other countries? And how do regional associations (e.g., ASEAN, Belt and Road Initiative) affect these international relationships?
96. How can we improve transboundary cooperation on environmental impact assessments for projects that span multiple nations, e.g., Upper Mekong dams?

POLLUTION – DRIVER

97. What and where are the most vulnerable ecosystems to environmental pollution (e.g., acid deposition, eutrophication)?
 98. What are the impacts of pesticides used on a large scale in plantations on invertebrates?
 99. What are the sources (geographic and sector) of plastics entering the environment?
 100. **What are the ecological effects of haze resulting from forest fires in the region on terrestrial and marine ecosystems?**
-

231 **DISCUSSION**

232 Our identification of the top 100 questions for biodiversity conservation in SE Asia and the themes
233 that emerged give an overview of research areas that experts commonly identified as priorities for
234 SE Asia. Of those considered biodiversity-loss drivers, the most “populous” ones, i.e., with the most
235 questions, are (1) wildlife harvesting and (2) agricultural expansion (illustrated in Fig. 1). This
236 outcome mirrors Maxwell et al.’s (2016) breakdown of the main global drivers of loss for threatened
237 and near-threatened species. However, by emphasising both issues more than Sutherland et al.’s
238 (2009) global list does, our exercise suggests they are especially important in the region.

239 The theme of **wildlife harvesting** (including of flora) is dominated by questions about the trade (legal
240 and illegal), which threatens (animal) biodiversity in SE Asia more than in any other region (Nijman
241 2010; Rosen and Smith 2010), and the basic nature of some of them shows how little is known.
242 Before assessing the effectiveness of interventions (as several questions call for), we must quantify
243 the volume of the trade and identify where it is occurring and who is involved. There is also a need
244 to understand exploitative activities on the ground (as highlighted by Q19). For example, the
245 practice of trapping songbirds for the caged bird trade is poorly documented even though it is
246 driving several Indonesian species to extinction (e.g., Bergin et al. 2017; Harris et al. 2016). It is also
247 worth noting that the trade does not just involve SE Asian species. For example, the trade in rhino
248 horn mainly flows from South Africa to Viet Nam (Milliken and Shaw 2012), and Singapore is a major
249 shipment hub and consuming country of African parrots (Poole and Shepherd 2016). Therefore,
250 tackling some of these questions in SE Asia stands to benefit the conservation of biodiversity outside
251 the region, and we hope new tools being developed (e.g., Di Minin et al. 2018) will make doing so in
252 the digital age easier.

253 The issue of **agricultural expansion** in SE Asia has received substantial research attention (e.g.,
254 Laurance et al. 2014; Wilcove et al. 2013) and there has been progress in mapping specific threats
255 and conversion of forests to human land uses (Gaveau et al. 2014; Hughes 2017b; Miettinen et al.
256 2011; Richards and Friess 2016). However, the state of affairs is far from an ideal scenario in which
257 fragmentation of forests by infrastructure and specific maps for each crop replacing them are
258 remotely monitored in real-time, or at least often enough to elicit meaningful action. This data gap
259 in mapping, combined with limited comprehensive information about locations of concessions,
260 hinders progress in four critical areas: (1) assessing the drivers of deforestation and degradation in
261 PAs and other KBAs, (2) determining the effectiveness of interventions, such as certification schemes
262 (but see Carlson et al. 2017; Cattau et al. 2016; Morgans et al. 2018), (3) predicting where crops will
263 expand next and (4) implementing conservation planning that accounts for this expansion. The
264 mapping gap is compounded by scarce data on the ground. The effects of interventions that provide
265 land tenure to smallholders or enable planting of higher-yield varieties and the role of corruption
266 remain equally poorly understood.

267 Our top 100 list also features **climate-change** as a key theme, albeit with a lower proportion of
268 questions than in the global research priorities list (Sutherland et al. 2009) or the list for Oceania
269 (Weeks and Adams 2017). However, considering relative retention rates and numbers of questions,
270 our list emphasises climate change over **infrastructure** or **pollution** – in contrast to Maxwell et al.’s
271 (2016) finding that it was the lesser of the three threats for threatened and near-threatened species.
272 In SE Asia, some thorough work has been done on birds (e.g., Bagchi et al 2013, Harris et al 2014),

273 but our questions illustrate the need to identify the most vulnerable species and systems and
274 produce data that can help predict responses. This knowledge is critical to planning and adaptively
275 managing mitigation strategies (e.g., PA networks, corridors) that maximise the abilities of
276 vulnerable species to disperse and persist (see also Heller and Zavaleta 2009). As suggested by Qs
277 63, 64, 65, researchers must also investigate interactions between climate change and other
278 conservation threats, especially given that the impacts of these interactions in SE Asia likely vary
279 greatly depending on the location, taxon and research question asked (Mantyka-Pringle et al. 2015).

280 Indeed, climate change is deeply related to the themes of **pollution** and **infrastructure**, both of
281 which are very problematic in SE Asia given its rapid development and rising consumption. Basic
282 knowledge of how, where and the extent to which plastics, pesticides, acids and nutrients affect
283 ecosystems is still lacking, although recent work found SE Asia's reefs to be highly contaminated with
284 plastic, with clear links to coral disease (Lamb et al. 2018). There is also a need to understand how
285 existing and future infrastructure projects, especially dams and roads, affect biodiversity – that is if
286 impacts are to be minimised or mitigated (Clements et al. 2014). International coordination for large
287 projects, such as the Belt and Road Initiative (Lechner et al. 2018), will be critical, especially when it
288 comes to transparent and evidence-based environmental impact assessments.

289 Even though our experts pinpointed the five threats above as the most pressing (based on numbers
290 of questions), the emergence of a theme whose questions aim to **document the loss of biodiversity**
291 **and its drivers** again reveals the need for the most basic knowledge (e.g., rates of extirpations,
292 locations and reasons for the loss of species). Some questions raise underlying issues not specific to
293 SE Asia. For example, Q61 (like Q6 and several others in Table S1) reflects the fact that some species
294 go overlooked or underserved by conservation efforts due to the use of surrogate species (e.g.,
295 Andelman and Fagan 2000; Douglas and Winkel 2014), though this may also result from the decline
296 of taxonomy (Hopkins and Freckleton 2006). Other questions depict issues that may be especially
297 pressing in SE Asia. One (also raised in Q13 and others in Table S1) is that the region's limestone
298 karst areas, despite being sensitive ecosystems with very high rates of endemism, are (1) poorly
299 protected and (2) more severely threatened by cement-quarrying than karst habitats elsewhere
300 (Clements et al. 2006).

301 Two themes revolve around practice-based interventions: **PAs** and **restoration**, with the former the
302 most “populous” theme of all. Our emphasis on PAs is unsurprising – PAs are the main conservation
303 tools worldwide – but it contrasts with earlier lists (Sutherland et al. 2009; Weeks and Adams 2017)
304 which contained few questions on PAs. Although their effectiveness has been assessed by remote-
305 sensing in some ASEAN countries (Gaveau et al. 2009; Papworth et al. 2017; Santika et al. 2015),
306 questions remain about their biodiversity coverage (especially for less-studied taxa) and ongoing
307 destructive activities within them. Therefore, researchers should engage PA managers to assess the
308 situation on the ground and document actual enforcement, and perform biodiversity surveys,
309 analyses of threats and formal studies of how well PAs are managed (Coad et al. 2015). Further, with
310 SE Asia identified as the region in which the conservation outcomes of PAs are most likely to be
311 hindered by conflicts between their objectives and needs of locals (Oldekop et al. 2015),
312 conservationists must determine the best way to ensure they provide socioeconomic benefits too
313 (e.g., Bennett and Dearden 2014).

314 Despite being less “populous”, **restoration** had the second-highest retention rate of all themes. This
315 may reflect a general expansion of conservation practice. Where anthropogenic pressures on
316 biodiversity are especially intense – as in SE Asia (see also Hughes 2017a) – it makes sense to focus
317 on species still present in disturbed habitats, e.g., selectively-logged forests (Giam et al. 2011), and
318 on restoring degraded land (Gibson et al. 2011; Sodhi et al. 2010b) instead of just aiming to preserve
319 “pristine” habitats. However, as our exercise shows, obstacles to doing so include identifying the
320 locations of degraded land in SE Asia, predicting where restoration efforts will be most cost-effective
321 and determining the best approach to restore abandoned plantations and complex systems (e.g.,
322 degraded peatland).

323 Of course, the success of any conservation intervention (e.g., planning reserves and corridors,
324 establishing quotas for sustainable harvests) demands solid ecological knowledge of the systems to
325 be protected or restored. The theme of **ecosystem function** (including the fact that it was more
326 populous than that of PAs in the total pool) reveals fundamental knowledge gaps. For example, we
327 still do not fully grasp the ecological consequences of biodiversity loss in SE Asia, e.g., for seed
328 dispersal (see also McConkey et al. 2012) or (as suggested by Q43) the emergence and prevalence of
329 disease (Pienkowski et al. 2017). Nor are we sure of species-specific habitat requirements (in
330 amount, configuration and quality) in fragmented landscapes. Riparian reserves within agricultural
331 monocultures seem important to certain SE Asian taxa, but their necessary dimensions and
332 contributions to connectivity and conservation of biodiversity are just beginning to be understood
333 (Giam et al. 2015; Mitchell et al. 2018).

334 Twenty questions in our top 100 are in the themes of **ES & human wellbeing, social interventions**
335 and **organisational systems and processes**, and some questions in other themes also target human /
336 social outcomes. Furthermore, the theme of ES & human wellbeing was the most populous one in
337 our total pool. However, compared to research priority lists for the world (Sutherland et al. 2009)
338 and Oceania (Weeks and Adams 2017), our top 100 list has relatively fewer questions in all these
339 themes. Still, our exercise (the set of questions and their links to the SDGs) clearly reveals expert
340 consensus that people are at the heart of SE Asia’s biodiversity crisis and its solution.

341 We point out the pressing need to document **ES and the extent to which livelihoods rely on them**,
342 especially to fill gaps relating to valuating ES such as pollination and flood control. Such knowledge
343 could help avoid market failures caused by policies that do not capture the importance of Nature to
344 SE Asian communities (Brander et al. 2012; Leimona et al. 2015). It is equally pressing to develop
345 well-informed **social interventions** given that outreach and education can change the conservation
346 attitudes and practices of SE Asians, e.g., promoting respect for PAs (Sodhi et al. 2010a), decreasing
347 hunting (e.g., Steinmetz et al. 2014). The challenge lies in discovering how to tailor interventions to
348 one of the most ethnically and culturally diverse regional publics (Clarke 2001) and especially to
349 create inclusive strategies that engage indigenous and other marginalised people (e.g., Ferse et al.
350 2010; Putz et al. 2012). These research questions are no doubt only answerable by borrowing
351 methodologies from psychology and behavioural economics.

352 Questions in the theme of **organisational systems and processes** revolve around bridging the gap
353 between research and decision-making and transboundary cooperation. With telecoupling on the
354 rise, so too are the benefits of enhanced collaboration among ASEAN nations on conservation issues
355 (Runting et al. 2015). Such collaboration is especially critical for species whose ranges cross borders,

356 i.e., migratory birds (Yong et al. 2017) and bats (Epstein et al. 2009), marine wildlife and large
357 mammals (Woodruff 2010). It is also key to tackling the wildlife trade (e.g., Sodhi et al. 2011) and
358 recurrent failures in managing the global commons, as exemplified by the challenges of handling fire
359 and haze (Lee et al. 2016).

360 Finally, the emergence of a theme on the **trade-offs between conservation and development** is
361 telling. Its questions (as do several others) call for cost-benefit analyses and/or spatial planning to
362 reconcile multiple demands on Nature (see also Koh and Ghazoul 2010), much like the outcome of
363 mapping our questions to the relevant SDGs. This speaks to the crux of the conservation conundrum
364 – how much biodiversity can we “save” while minimising opportunity costs to development.

365 We initiated this priority-setting exercise on the basis that it would offer *new* information, i.e., that
366 research needs for biodiversity conservation and sustainable development are context-dependent
367 and that SE Asia’s are therefore, at least to some extent, unique. A comparison between our top 100
368 questions and those identified by prior exercises corroborates this. For instance, of the top 100
369 global questions (Sutherland et al. 2009), only 16 are like ours. Some are narrowly similar, e.g., its
370 Q21 (How will climate change affect global food production, and what are the resulting
371 consequences for ecosystems and agrobiodiversity?) is very like our Q66. Others are only broadly so,
372 e.g., its Q29 (What are the human well-being costs and benefits of protected areas, how are these
373 distributed, and how do they vary with governance, resource tenure arrangements, and site
374 characteristics?) is somewhat like our Q11. Similarly, of the 38 questions for Oceania (Weeks and
375 Adams 2017), seven were narrowly or broadly similar to questions in our top 100. However, one of
376 the most striking differences between our exercise and previous ones (e.g., Kark et al. 2016; Rudd et
377 al. 2010; Sutherland et al. 2009; Weeks and Adams 2017) is the emergence of wildlife harvesting and
378 agricultural expansion as major themes – with 24 of our top questions. These are the same two
379 drivers that Sodhi et al. (2004) identified as posing the biggest risk to biodiversity in SE Asia. Indeed,
380 the fact that SE Asia’s rate of deforestation is higher than that of any other region and is accelerating
381 is largely attributable to the growing market for agricultural commodities (Wilcove et al 2013). But
382 even where forests remain intact, hunting is often so intense that they are being emptied of wildlife
383 – a problem driven largely by the often illegal trade (Nijman 2010).

384 *Limitations and challenges*

385 Identifying top research priorities for conservation and sustainable development in SE Asia remains a
386 useful exercise, but with some limitations. The main, unavoidable, one is that the pool of questions
387 necessarily reflects the pool of contributors, whose characteristics are a potential source of bias. For
388 instance, more than half of invited contributors declined to participate, and we did not identify the
389 factors behind this self-selection bias.

390 Another source of bias is the fact that all but two contributors were affiliated with universities, other
391 research institutions and NGOs – most of whom focus on biodiversity conservation. It would be ideal
392 if future exercises included more diverse participants, especially decision-makers and more people
393 who do conservation work on the ground (Game et al. 2013). Indeed, had our authorship consisted
394 of different stakeholders, such as agribusiness leaders or government representatives, perhaps the
395 set of questions would have been more anthropocentric and focused on human development issues
396 and less so on threats to biodiversity. Still, we set out to generate a list of priority **research**
397 **questions**, and because we expected researchers to be the people most familiar with research gaps,

398 we solicited their participation, as prior exercises have done (e.g., Kark et al. 2016 and others cited
399 therein). Moreover, our list contains roughly equal numbers of descriptive and proactive questions,
400 signifying our aim to suggest research directions that will ultimately trigger meaningful, durable
401 change (see also Kark et al. 2016).

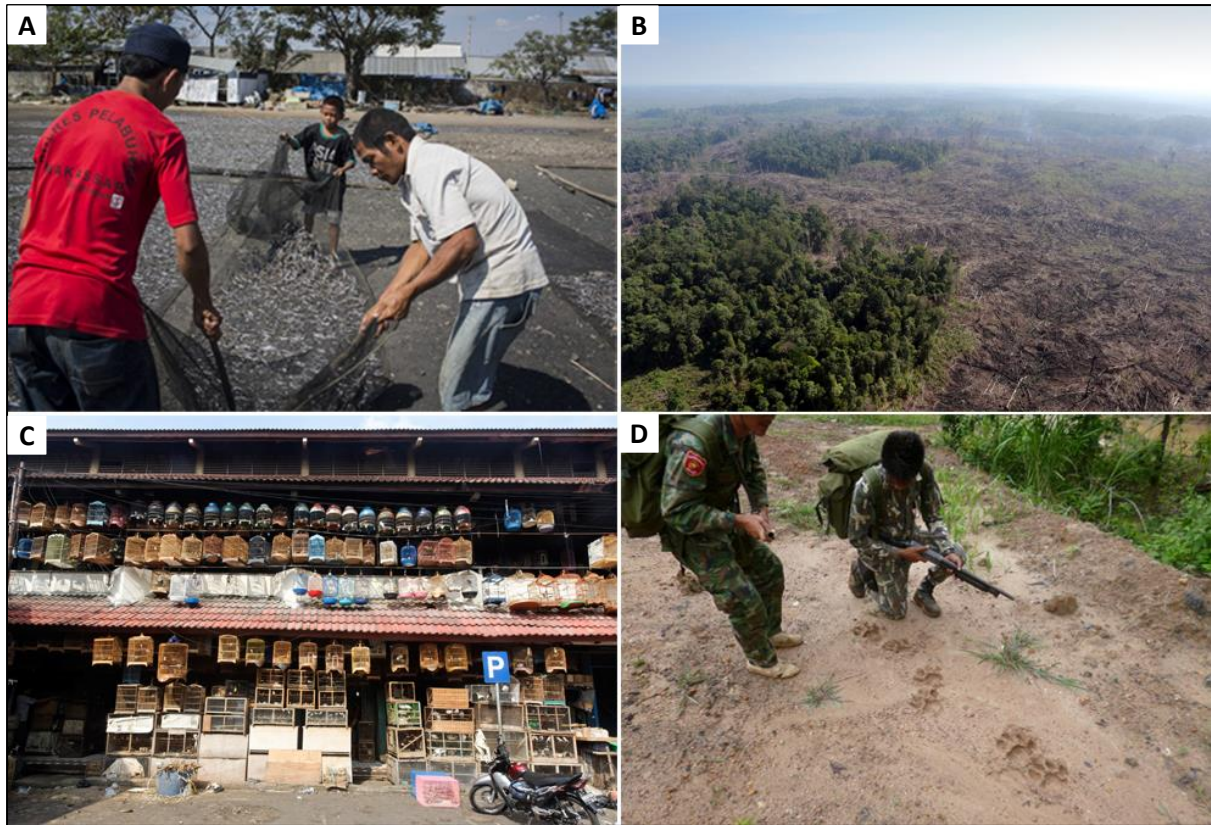
402 Finally, like most research-priority setting exercises (see also Sutherland et al. 2011), ours was biased
403 by the areas of expertise of our contributors. Biome-wise, about 14 % were freshwater or marine
404 experts. This bias could explain why few of our questions specifically address aquatic issues.
405 However, it also mirrors that of the broader research community, with 72 % (Hendriks and Duarte
406 2008) to 83 % (Tydecks et al. 2018) of biodiversity studies focusing on terrestrial systems, and
407 research-priority setting exercises typified by low emphasis on aquatic issues (Kark et al. 2016).
408 Specialisation-wise, our group was dominated by conservation biologists/scientists, and then
409 geographers, even though we also targeted sustainable-development experts in our Google Scholar
410 search. Geographically, although our contributors included experts who do research in most ASEAN
411 countries or in SE Asia generally, we failed to engage any specifically based in Cambodia, Lao PDR
412 and Myanmar – the same ASEAN countries that Giam and Wilcove (2012) identified as being most
413 lacking in published conservation research.

414 Given these caveats, our top 100 list (and even the total pool of questions in table S1) should be
415 viewed as a subset of all key questions that could have been identified. Nonetheless, we believe our
416 outcome represents a large proportion of important questions shared by conservation researchers
417 and practitioners in the region.

418 **Conclusion**

419 Our top 100 priority research questions depict SE Asia as a region in which extreme pressures on
420 biodiversity occur and interact with each other in complex and poorly-understood ways. It also
421 depicts regional problems of (1) scarce conservation funding (Wilson et al. 2016), especially for
422 transboundary research given the lack of an effective ASEAN-wide funding agency and (2) low
423 governmental prioritisation of biodiversity research (see also Woodruff 2010). In this context, on-
424 the-ground information, e.g., on species distributions, livelihoods or threats, is especially valuable.

425 Finally, the basic nature of several of our top 100 questions (and of others in the total pool) seems
426 symptomatic of an insidious problem. There is less conservation-relevant research being done (and
427 published) in SE Asia than in many other regions – the result of insufficient funding and capacity,
428 especially in the lowest-income countries (Giam and Wilcove 2012). Therefore, we hope this paper
429 will stimulate the development of useful studies to engage a generation of SE Asian researchers,
430 whose work will meaningfully advance the urgently-needed conservation of SE Asia's biodiversity.
431 Moreover, we hope it provides useful suggestions on how to bridge the research-implementation
432 gap, so that research outcomes can be communicated to decision-makers, operationalised and
433 translated into action.



434

435 Fig. 1. Images illustrating four biodiversity-loss drivers identified as key priority research themes.

436 A) People collecting seafood in a coastal area of Makassar, Indonesia, illustrating the problem of
 437 unsustainable wildlife harvesting; Conor Ashleigh/The Asia Foundation, 2014.

438 B) Slash and burn agriculture occurring within Tesso Nilo National Park, Indonesia, illustrating the
 439 issues of illegal deforestation for agriculture and the SE Asian haze; Rhett Butler, 2015.

440 C) Pramuka bird market in Jakarta is one SE Asia’s largest – more than 16,000 individual birds were
 441 observed to be for sale over a three-day period (Chng et al. 2015) – illustrating the scale of the
 442 wildlife trade – the greatest conservation threat to many SE Asian species, including many songbirds;
 443 Michael Lane © 123RF.com.

444 D) Forest guards track tiger tracks in Thailand, where the threat of poaching exists even within
 445 protected areas; Gregory McCann, 2013.

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