Top 100 research questions for biodiversity conservation in Southeast Asia

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Top 100 research questions for biodiversity conservation in Southeast Asia

Abstract

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

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

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

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

INTRODUCTION

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

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

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

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

METHODS

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

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

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

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

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

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

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

RESULTS

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

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

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

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

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

Table 1

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

	PROTECTED AREAS (PAs) – PRACTICE-BASED INTERVENTION
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)?
	WILDLIFE HARVESTING – DRIVER
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?**

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DISCUSSION

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Limitations and challenges

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

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

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

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

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

Conclusion

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

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

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

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

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

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

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

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