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Title

The Importance of an Interdisciplinary Research Approach to Inform Wildlife Trade Management in Southeast Asia.

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Abstract

Wildlife trade represents a major threat to endangered species populations, especially in Southeast Asia where trade continues at high levels despite increased efforts to control illegal activities. To identify management strategies that better mitigate the threat of this trade, research must address knowledge gaps about the complexity of established trade networks. This requires a comprehensive and interdisciplinary approach that integrates biological, anthropological, socioeconomic, and other kinds of data and involves multiple stakeholders across sectors. We present here an interdisciplinary research framework for developing such an approach. Our integrative framework, based on the Social-Ecological

Systems Framework by Ostrom, can be used to explore and untangle complex wildlife trade dynamics across scales, and test hypotheses derived from different disciplines to provide robust recommendations for trade management. We also discuss the need for developing databases for trade-targeted species and outline steps to build and strengthen technical and interdisciplinary capacity to support the integrative framework.

Keywords: wildlife trade, Vietnam, Indochina, social-ecological system, systems thinking

Introduction

Overexploitation of wildlife to supply domestic and international trade is a global threat to biodiversity conservation goals. In particular, it has been recognized as the single largest threat to biodiversity in many Southeast Asian countries, where increasing wealth and demand for wildlife products correspond with low levels of enforcement (Bennett 2011, Nijman 2010, TRAFFIC 2008).

A large volume of wildlife is traded internationally; each year consumers in China, Europe, Japan, and the U.S. purchase billions of dollars' worth of wildlife products from Southeast Asia (Nijman 2010). However, wildlife is also traded locally or nationally, and hunting for subsistence and traditional medicines are long established traditions in Southeast Asia and also provide sources of income (e.g. Nekaris et al. 2010). Reductionist management of wildlife trade not only impedes goals related to environmental sustainability but also goals related to health, poverty, and hunger (TRAFFIC 2008). On the other hand, wildlife trade has significant negative implications and is known to synergize

69 with other threats to biodiversity: hunting and trade increase as access to forests increases
70 through other mining or extraction efforts (e.g. Suarez et al. 2009), and zoonotic viruses are
71 often associated with illegally imported wildlife products (Greatorex et al. 2016). Wildlife
72 trade has also been connected with conflict and national security issues (Douglas and Alie
73 2014).
74 Despite increased media attention to the problem, collaborative actions on the ground
75 (e.g., the establishment of the ASEAN Wildlife Enforcement Network in 2004), and
76 international commitments to tackle illegal wildlife trade (e.g., the London Declaration, and
77 Kasane and Hanoi Statements), wildlife trafficking continues at high levels (Hanoi
78 Statement on Illegal Widlife Trade 2016, UNODC 2016). Many researchers and officials
79 agree that existing regulatory top-down or "command and control,'" policies are failing in
80 this region and changes are necessary to work towards sustainable resource use (CITES
81 Vietnam 2008, TRAFFIC 2008). Bennett (2011) argues that regulatory-based interventions
82 remain the best approach because the greatest driver of trade is wildlife demand from
83 wealthy consumers in East Asia; in other words, the major problem is not the type of
84 intervention but rather the gaps in capacity and resources to enforce existing regulations.
85 However, the ubiquity of the trade makes it impractical to govern using regulatory-based
86 interventions alone (CITES Vietnam 2008, TRAFFIC 2008); to work more effectively
87 towards sustainability, research must assess how feasible other non-regulatory incentives
88 and interventions might be, including market-based instruments (Jepson and Ladle 2009),
89 which some argue may have a greater chance of being equitable and effective. However,
90 bold supply-side strategies including regulated trade, ranching, and wildlife farming

91 remain hotly debated regarding both their application in Southeast Asia (Brooks et al.
92 2010, Drury 2009) and at a global scale (Phelps et al. 2014).
93 Behind each of these arguments are assumptions about the specific set of drivers of
94 wildlife trade in Southeast Asia. In Africa and in the Neotropics, several studies have shown
95 how wild meat over-exploitation is driven by poverty (e.g. Brashares et al. 2011, Wittemyer
96 2011), a lack of alternatives to wild protein (Foerster et al. 2011), conflicts and
97 displacement (e.g. Wittemyer 2011), and the implementation and choice of enforcement
98 measures and policies (e.g. Nyaki et al. 2014). This is not to say that the drivers of
99 overexploitation in these regions have been completely clarified; recent work highlights
100 how assumptions and limited contexts regarding definitions of poverty have restricted
101 researchers' understandings of motivations for illegal hunting (Duffy et al. 2016).
102 To avoid the development of management efforts and intervention measures in Southeast
103 Asia on assumptions based on thin evidence (Nadal and Aguayo 2014), several knowledge
104 gaps should be addressed towards characterizing the highly variable and complex wildlife
105 trade chains and socioeconomic drivers of trade (Lee et al. 2014; TRAFFIC 2008). In part,
106 the complexity of wildlife trade in Southeast Asia stems from traditional uses and cultural
107 values relating to wildlife and wildlife products (Donovan 2004). For example, some
108 studies indicate that wealth and social status appear to be stronger drivers of wildlife trade
109 in Southeast Asia than poverty, with urban consumers driving demand for wildlife
110 products more than local subsistence in some cases (e.g. Drury 2011, Sandalj et al 2016).
111 However, other studies show that most wildlife is still traded locally in rural regions (e.g.
112 Nijman 2010), meaning that further complexity may not be addressed by research that
113 focuses solely on urban consumers. There are diverse actors with multiple cultural

114 backgrounds along trade chains in Southeast Asia and their actions are likely shaped by
115 factors that vary from site to site, including financial gain, social esteem, cultural identity,
116 and customs, among others (MacMillan and Nguyen 2014, Nekaris et al. 2010). Thus,
117 different policy incentives and interventions may be effective at different points along the
118 trade chain and in different locales, and research aimed at informing wildlife trade
119 management should take into account the possibility of spatial and cultural heterogeneity
120 in potential trade drivers at multiple scales.

121 We argue here that interdisciplinary research approaches that integrate socioeconomic,
122 anthropological, psychological, governance, and biological data across multiple scales are
123 necessary to understand the characteristics of wildlife trade dynamics and effects. Others
124 have made similar arguments about how to improve research approaches for studying the
125 links between poverty and illegal wildlife hunting (Duffy et al. 2016) and for studying
126 'conservation crime' more broadly (Gibbs et al. 2010, Gore 2011). These authors note the
127 importance of studying the structural contexts of hunting holistically, questioning
128 assumptions about key variables and concepts, and capturing historical social, economic,
129 and political contexts (Duffy et al. 2016). The need for interdisciplinary, holistic research
130 approaches is of particular importance given the complex cultural, political, economic, and
131 social contexts of Southeast Asia (McElwee 2004). However, what is needed to
132 operationalize this idea?

133 Recent papers have articulated the utility of a social-ecological systems framework to
134 study sustainability of hunting for meat at local-site scales (van Vliet et al. 2015). Here, we
135 describe a social-ecological systems framework to design an interdisciplinary research
136 approach to study the illicit wildlife trade regionally and across scales in Southeast Asia. A

common analytical framework that can be applied and understood across disciplines is especially necessary in cases such as the Southeast Asian wildlife trade, where knowledge and theories from different disciplines are required to understand dynamic trade systems. The framework we present here is designed to guide holistic study of complex wildlife trade systems, including to explore variables, question assumptions, and design interdisciplinary research questions. We focus on Southeast Asia because 1) there is an established need to fill knowledge gaps about wildlife trade in this region and 2) this region exhibits the complex cross-scale dynamics that can illustrate why an interdisciplinary research approach is so critical to guide research on wildlife trade. However, our framework is flexible enough to be applied in other regions as well.

We discuss steps taken and planned towards developing an interdisciplinary analysis of the pattern, scale, and drivers of trade in key targeted species in Indochina/Vietnam, a hotspot for the Southeast Asian trade network, as examples for how to implement the framework. We highlight examples of cases where, without a framework or rigorous integration of methods and data from different disciplines, researchers might draw the wrong conclusions, which would lead to misdirection of wildlife trade management efforts. We also argue for building and strengthening technical and interdisciplinary capacity to implement the approach, including the enlistment of DNA barcoding and integration of social science approaches.

An Interdisciplinary Research Framework

The dynamic complexity of wildlife trade in Southeast Asia highlights the need for an interdisciplinary research framework to guide academic study of the trade and inform management decisions. An ideal framework would enable systems level conceptualizations,

160 or 'systems thinking,' to identify and analyze linkages among complex system elements.
161 Emphasizing interrelationships, feedback loops, nonlinearities, and time delays, among
162 other systems principles, promotes iterative analyses of a system's dynamic connections
163 and interactions towards a better understanding of the whole system, thus informing an
164 understanding of its components (Sterling et al. 2010).
165 The need for dynamic models and frameworks to understand complex systems has been
166 established (Costanza et al. 1993), as has the need to integrate knowledge and theories
167 across disciplines for effective biodiversity management (Watzold et al. 2006). Elinor
168 Ostrom's Social-Ecological Systems (SES) Framework, which organizes multiple, diverse
169 variables across scales, represented a leap forward towards an interdisciplinary
170 framework for empirical studies (Ostrom 2009). The SES framework enables formal
171 exploration of dynamic, nonlinear linkages and interactions among variables across scales
172 to better understand system outcomes. Being theory-neutral, a SES framework can also
173 facilitate exploration of variables that might be derived theoretically from different
174 disciplines, and of how assessments based only on biological or social data alone may lead
175 to divergent interpretations of the system (Leslie et al. 2015, Schlüter et al. 2014).
176 Our interdisciplinary conceptual framework (Figure 1) groups variables derived from
177 different disciplines within system components, or first-tier variables, as in Ostrom's SES
178 Framework (McGinnis and Ostrom 2014, Ostrom 2009). Second-tier variables or attributes
179 facilitate analysis of wildlife trade in Southeast Asia. To characterize resource units and
180 resource systems, variables stem from biological data and models at varying scales. This
181 includes, for example, the genetic and morphological diversity as well as the population
182 status and distribution of resource units (Figure 1). Anthropological, psychological,

183 governance, and economic data and models inform understanding of the behavior and
184 decisions of actors, as well as the nature of relevant governance systems. Variables could
185 include, for example, the economic and cultural values actors place on traded species, social
186 networks of actors (in different hierarchical groupings, as noted by McGinnis and Ostrom
187 2014), access to education and technology, laws and knowledge of laws, and infrastructure
188 related to enforcement and transportation. We describe analysis of process relationships,
189 interactions, and outcomes to operationalize the framework into mathematical model(s) in
190 the next section. Related ecosystems and additional social, economic, and political settings
191 are considered external to the focal SES analyzed, but are relevant for broader context
192 (Figure 1).

193 **Iterative Exploration across Disciplines**

194 Our integrated framework enables exploration of variables and datasets that combine
195 biological information of trade-targeted populations with other information on how people
196 engage in the trade of these populations at multiple scales. Selection and outlining of
197 second-tier variables and attributes can be helpful to explore the dynamics and
198 interconnections of a system across scales, test assumptions about drivers of wildlife trade,
199 and test combined policy interventions to identify points and locations in the trade chain
200 where interventions are likely to have the greatest impact. We explore below some
201 examples of how integration and exploration of different disciplinary approaches and
202 technologies illuminate the complexity of wildlife trade in Southeast Asia:

203 *Biology*

204 Two major problems for law enforcement and study of taxa in the trade are species
205 identification and product provenance, often because products have been processed before

206 being sold in markets. Sophisticated techniques can help in assigning species and in
207 identifying wildlife products (Alacs et al. 2010, Ogden et al. 2009). DNA barcoding, for
208 instance, has been used successfully over several years for many different groups of plants
209 and animals (Eaton et al. 2010, Dawnay et al. 2007, Hebert et al. 2003). This technique has
210 not been applied widely in Southeast Asia due to limited access to molecular laboratories.
211 The situation is expected to change quickly as DNA amplification and sequencing have
212 become more accessible and inexpensive. Indeed, a growing number of wildlife trade
213 studies in Asia employ DNA to investigate species under threat (e.g. Chen et al. 2015, Zhang
214 et al. 2015). By combining DNA barcoding with morphological, anthropological, and
215 socioeconomic data, researchers can clarify the patterns, scales, and drivers of wildlife
216 trade, determine hotspots of trade activities, and taxa under critical pressure.
217 *Anthropology*
218 Non-economic social and cultural elements are often neglected in studies that integrate
219 ecological and economic factors for decision-making (Fagerholm et al. 2012) and social,
220 cultural, and political contexts can play significant roles in supporting or preventing
221 wildlife trade (Figure 1). Strong governance, regulations, and enforcement of regulations,
222 for instance, can vary across regions, as can cultural norms regarding trade. Better
223 understanding of why and when individual actors participate in trade – what social and
224 cultural forces and norms drive hunting, subsistence uses, and market activities, such as
225 valuing of rarity or connection to identity – is critical to sustainable management and
226 situated governance. For example, slow lorises (genus *Nycticebus*) seem to be subject to
227 opportunistic or incidental exploitation for uses that vary widely from meat to medicine to
228 pets depending both on the ethnic group and the region under study (Thach et al. In

229 review). Also, methods such as social network analysis, developed first in sociology but
230 used in anthropology and other fields, can be applied to explore the importance of social
231 networks as drivers and operators of wildlife trade chains (Freeman 2004).

232 *Economics*

233 Traditional economic models are anthropocentric and analyze human uses of ecosystems
234 for production and consumption activities. In contrast, over the past two decades there has
235 been a spate of interest in bioeconomic modeling, an exercise that employs both economic
236 and biophysical components, largely through the application of econometrics. Although
237 econometric models have been applied to the bushmeat trade in Africa (e.g. Fischer et al.
238 2011, Skonhoft 1998), analyses of the Asian wildlife trade to date have been limited to
239 characterizing trade chains or quantification of species, consumption patterns, and profits
240 in trade at particular locations (e.g. Sandalj et al. 2016, Shairp et al. 2016); very few studies
241 have used models to illustrate broader or more complex trade dynamics across sites.

242 While such interdisciplinary empirical analyses constitute a step in the right direction,
243 successful integration of ecological phenomena remains a major challenge due to sharp
244 differences in disciplinary foci, mindsets, and vocabulary. This is beginning to change,
245 however, with the advent of SES models. An important element of SES frameworks that has
246 not been examined in previous studies is how to operationally connect data, hypotheses,
247 and questions from different disciplines. The interdisciplinary SES framework that we
248 outline in Figure 1 can also be used to iteratively investigate different assumptions
249 supported by data from any discipline included in the framework, and to pinpoint key
250 interactions and outcomes of the system. For example, if there is initial evidence from
251 interview-derived data suggesting that trade products are transported from southern to

252 northern Vietnam, it can be articulated as a preliminary hypothesis. This hypothesis can be
253 further supported using patterns inferred from forensic DNA barcoding of trade
254 confiscations, or another biological approach (Figure 2). Other types of data (e.g.
255 transportation information) can be used to further triangulate the nature of interactions
256 and outcomes along this dimension of the system.

257 **Operationalizing the Framework**

258 SES models developed from the perspective of a single discipline, such as resource
259 economics, applied ecology, or fisheries science, tend to oversimplify either the ecological
260 or the social domain, and often fall short in exploring and explaining the social-ecological
261 feedbacks that drive the development of the coupled SES (Schlüter et al. 2014). In
262 particular, the 'Ecology' component of the SES framework has been underdeveloped; yet,
263 policy recommendations are more likely to stem from SES research that includes both
264 ecological and social variables (Rissman et al. 2017). Under an interdisciplinary SES
265 framework as proposed in Figure 1, process and pattern oriented sub-models or
266 component models for different system components or variables (e.g., econometric
267 dichotomous choice models to predict actor behavior in relation to hunting) can be
268 bundled into a suite of models using knowledge and theories from diverse disciplines to
269 further explore interactions and outcomes at various scales (Figure 1).

270 Challenges to the operationalization of SES frameworks via quantitative or semi-
271 quantitative models (such as process-oriented, decision, general equilibrium, general
272 algebraic systems, dynamic systems, fuzzy-logic cognitive mapping, or input-output
273 models) include parameterization of dynamic processes to account for scale as well as
274 cultural, biological, and economic change; and integrating spatially explicit variables with

other factors. Recent operationalization of SES frameworks into models have accounted for dynamic scales by distinguishing between different levels of aggregation, e.g., individual actors vs. groups of actors, and individual resource units vs. populations of resource units (Hinkel et al. 2014). Others have clarified hierarchies of process relationships and interactions among components through influence diagramming and top-down unpacking of process relationships until changes in all relevant variables are explained (Schlüter et al. 2014). Making explicit underlying assumptions of component and systems models will be particularly important to integrate effectively across inputs and assumptions that stem from the conceptual backgrounds of different disciplines (Schlüter et al. 2014).

Rather than prescribe a particular modeling or analysis approach to implement our framework, analysis should be tailored to the specific data-driven requirements of a given research question and associated considerations of statistical assumptions and power and should remain open to qualitative and thematic approaches. For example, below we describe our analysis under development for key trade targeted species in Indochina, where we are integrating regression approaches with qualitative analysis. Simply put, qualitative research can support "internal validity" (*sensu* Drury et al. 2011), meaning that data represent the phenomenon under study in complement to the "external validity" of quantitative data.

Key Trade-targeted Species

The Southeast Asian wildlife trade involves a huge diversity of plants and animals. Although we focus here on animal groups, plants are also heavily traded in Southeast Asia, but possibly at different scales and influenced by different socio-economic drivers (e.g., orchids and cycads – CITES Vietnam 2008). In terms of taxonomic groups, turtles,

298 pangolins, and snakes have been most traded internationally. Other heavily traded groups
299 include civet, muntjac, bear, primate, sambar, otter, and serow (Nguyen 2008,
300 TRAFFIC/WCS 2004). The abundance of many trade-targeted animal species in Southeast
301 Asia has declined severely over the past decade. However, in some cases local extinctions
302 may be linked to wildlife trade by little more than assumed association because key
303 information on distribution, taxonomy, and population status are lacking for many trade-
304 targeted species, especially in Vietnam/Indochina (CITES Vietnam 2008, Nguyen 2008,
305 TRAFFIC 2008, Benitez-López et al. 2017). Guidance from our SES framework might help to
306 prioritize data collection. For example, a great deal of trade data, e.g., number of seizures,
307 specimens, and species in the trade at both regional and local scales are available, but data
308 on population status of traded species is generally limited. The latter should therefore be a
309 focus of future programs to help link trade to local extinction of species and/or
310 populations.
311 Research that narrows on a suite of focal species could serve to investigate multiple
312 scales of trade within a hierarchical SES research framework. Candidate species groups
313 should be those for which wildlife trade is their major threat and that are subject to local,
314 regional, or international demand, advancing our understanding of the multiple scales of
315 wildlife trade in the region. In addition, data on their taxonomy, genetic patterns,
316 distribution, and the level of exploitation should be available for hypothesis testing within
317 the framework. In our work we have identified four focal groups of trade-targeted species
318 for which sufficient data are available as per categories above, yet differ in their relative
319 prevalence in trade across scales to test hypotheses about scales and drivers of wildlife
320 trade in Vietnam/Indochina: turtles, muntjacs, pangolins, and slow lorises.

With the exception of some of the turtles and muntjac species, these groups are overall widespread and taxonomically diverse. However, a majority of species in the two aforementioned groups is traded in two vastly different networks. While most turtle species in Mainland Southeast Asia are hunted for export, muntjacs are often consumed domestically (Nguyen 2008, TRAFFIC/WCS 2004, Authors' Unpublished data). Trade-targeted species, such as turtles and pangolins, are under immense pressures from rising demands of the international trade. As turtle and pangolin populations decline, their value in the trade is increasing at rates greater than inflation (Newton et al. 2008), exhibiting an 'anthropogenic allee effect' where extinction of rare species is influenced by human value attributed to rarity (Courchamp et al. 2006). Because of the nature of turtle and pangolin trade, namely their rarity and high price, all pangolins and turtles caught in local villages are sold to traders for sale in urban or international markets. Therefore, data on most turtle and pangolin trade may not be able to tell us very much about local scales of trade. On the other hand, muntjacs are suitable for studies examining the nature of the trade at the local scale because of their domestic consumption.

Slow lorises (genus *Nycticebus*) are small, nocturnal primates. Slow lorises are widespread, have naturally low densities, and are in high demand for traditional medicines, as pets, and for food and are also traded internationally for these purposes (Nekaris et al. 2010). Despite all slow lorises having protected status across their range, enforcement of this status remains quite neglected compared to other, higher-profile animals (Beyle et al. 2014). Importantly, traded species are not necessarily traded in isolation; a targeted species may be opportunistically, incidentally, or accidentally exploited when hunters are looking for more common, or other species (Branch et al. 2013). Because of their natural

344 low densities (rarity), slow lorises seem to be subject to opportunistic or incidental
345 exploitation, depending on the area under study (Thach et al. In review). More research
346 needs to be done both across and within species, in the latter case focusing on how the
347 same species could be exploited in different ways at different scales and by different
348 people. Data on highly targeted species alone may not be able to tell us very much about
349 other species, and it might be quite difficult to get unbiased information from hunters and
350 traders on the targeted species.
351 In our preliminary analysis on slow loris trade, iterative exploration including qualitative
352 methods and analysis of key informant interviews were essential to understanding why
353 people engage in trade and also to accurately characterize trade pathways. We have used
354 genetic information to identify a pygmy slow loris confiscated by Vietnamese authorities in
355 northern Vietnam as originating from southern Vietnam, supporting a trend of trafficking
356 from southern Vietnam to northern Vietnam (Cao Giang et al. In prep). Our interviews with
357 key informants confirm this trend but also suggest some movement from central to
358 southern Vietnam (Thach et al. In review). However, none of our confiscated samples from
359 southern Vietnam show genetic provenance from northern or central Vietnam. Together,
360 our datasets collected and integrated within our framework show a more complicated
361 spatial pattern of trade than would be inferred by using only one method, and have
362 inspired a next set of iterative research questions that could be answered by integrating
363 new sources of data within our integrative framework, such as transportation information:
364 Is trade more frequent in one direction than the other? Are prices and uses different in
365 trade going different directions? Where and how do intermediaries sort pricing and routes?
366 Interventions that might be informed by the outcomes of this research might include

activities targeted at sorting points that are tailored to the particular drivers in each direction, which may differ.

Building and Strengthening Technical and Interdisciplinary Capacity for Integrative Approaches

A key challenge in this effort will be building the capacity for effective interdisciplinary teams of researchers enabled to operationalize the iterative exploration of wildlife trade within a SES framework. Our framework originated in the lead authors' backgrounds in evolutionary biology, and to complete our framework development we built a team that includes anthropologists and economists. In addition, integration and increased collaboration with legal, anti-corruption, and governance research fields will be essential to bring the framework to action at multiple scales (Figure 1; e.g. Gibbs et al. 2010, Gore 2011). Interdisciplinary and international teams must negotiate conceptual differences, theories of knowledge, research ethics requirements, power dynamics, disciplinary prejudices, and challenges in communication, infrastructure, and logistics. Effective interdisciplinary collaborations require a great deal of work to implement, including team leadership that is committed to true conceptual integration among carefully selected team members who collaborate towards a co-created research question (Black and Copsey 2014, Pooley et al. 2014).

Although the integrative framework requires well-rounded research capabilities, we highlight here the need for strengthening key areas, which we argue currently fall short of the standard for quality interdisciplinary research especially in our region of focus. As a key component of the integrative framework developed here, DNA forensic and barcoding tools should be made widely available to facilitate wildlife trade management and

hypothesis testing for better understanding of critical parameters, e.g., scale, driver, and pattern, of the complex conservation threat (UNODC 2016). Recent advances in molecular technologies have led to a rapid increase in application of DNA barcoding and other assignment tools to wildlife trade (e.g. Eaton et al. 2010, Chen et al. 2015, Zhang et al. 2015). Recognizing the advantages of the method, Pakistan became the first country in Asia to adopt DNA barcoding as a technique to curb illegal wildlife trade (Shahid 2015). Other countries are also considering the use of DNA analyses as an official wildlife enforcement tool (TRAFFIC 2015).

Currently, however, infrastructure, such as comprehensive DNA databases, is not ready to support comprehensive use of the technique. GenBank data are not well curated, and many available sequences are missing key information, such as locality. The few available curated databases, e.g., DNA Surveillance and $DNA_{BUSHMEAT}$, only cover specific taxonomic groups, most often mammals (Gaubert et al. 2015, Ross et al. 2003). For other lesser known, but widely traded vertebrates, such as turtles and other reptile species, resources have not been developed. To better control the wildlife trade, it is critical to develop such a DNA database for range countries in Southeast Asia. As a first step, the database should have representatives of all vertebrates protected under the law in the countries for wildlife trade enforcement. DNA barcoding regions for the database could include the mitochondrial genes, cytochrome b or the cytochrome c oxidase subunit 1 (COI), because they are the markers of choice in wildlife forensic science (Alacs et al. 2010).

Other species that are currently not protected under law, but have been heavily traded, should also be included in the database in the likelihood that these species will be regulated in the future. More importantly, multiple sequences from geographically isolated

populations of the targeted species should be incorporated into the database to help determine trade patterns, hotspots of trade activities, or populations under a high level of harvesting pressure. Recent studies demonstrate that such a fine scale population assignment is particularly informative for wildlife trade management (e.g. Zhang et al. 2015), especially to trace geographic provenance and provide detail to supplement data from other disciplines within our integrative framework.

There are many challenges in developing a database for wildlife trade enforcement and research within the interdisciplinary framework. Its development requires collaboration between a wide variety of research institutions, including natural history museums, non-government organizations, universities, and other research institutes from different countries in the region. This involves establishing data sharing mechanisms among participating organizations. In addition, as funding for biodiversity research is in serious shortage (Amato and DeSalle 2012), this could prove a daunting task without support from governments and international funding agencies.

Conclusion

In summary, we believe that complex conservation problems merit interdisciplinary frameworks such as the one we have developed and described here. Our framework will allow researchers to test assumptions about how different aspects of a system interact and where there are non-linearities in feedbacks across scales and dimensions. Our approach is intended to guide holistic study of complex wildlife trade systems, rather than prescribe specific policy actions, which should be assessed by policymakers and managers in specific socio-political contexts based upon new information produced under the framework. However, the ideas put forward in our framework also relate to broader discussions in

conservation aimed at intervention design and planning. The Open Standards (OS) for the Practice of Conservation (CMP 2013) is a tool to facilitate adaptive management in planning, implementing, and monitoring conservation initiatives. The OS fosters transparency by making explicit assumed causal relationships between strategies and anticipated outcomes (Schwartz et al. 2012). Our framework could be helpful to inform the process by which teams come to and question their stated assumptions during the process of formulation, and help to promote systems analyses of problems. In the future, we expect to collaborate with more enforcement-focused organizations such as the Society for Wildlife Forensics to bridge holistic understanding guided by the framework to specific enforcement outcomes that avoid one-size-fits-all solutions and pinpoint where to invest effort to address problems such as wildlife trade in Southeast Asia.

Capturing the complexity of cross-scale interactions in a wildlife trade system does not mean that management needs to be so complicated and convoluted that it will no longer be feasible; different management strategies can be tailored to focus on different dimensions of the social ecological system, keeping in mind how they influence and are influenced by other aspects of the system (Sterling et al. 2010). This systems perspective helps to focus initial questions towards those that are tractable and appropriate and away from fixes that fail. Strategic management approaches can be targeted to the needs and strengths of specific regions or scales; for example, if variables related to local actors are found to be the most important drivers of trade at the local scale, interventions can focus on improving relationships among relevant stakeholders. If variables related to governance are found to be the most important drivers at the national scale, interventions may focus on improving institutional arrangements (Leslie et al. 2015). Capacity development and database

development and sharing will be key to acting on recommendations derived from the framework analysis in order to address the critical issue of wildlife trade in Southeast Asia.

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Figure Legends

Figure 1. An interdisciplinary conceptual framework identifying relevant components or first-tier variables (quarters of the circle, labeled on the outside of the circle), sub-components (inside the circle), and second-tier variables (below) to analyze wildlife trade with a focus on Southeast Asia, modeled after Ostrom (2007)'s Social-Ecological Systems Framework.

Figure 2. Iterative investigation of different research questions, assumptions, and hypotheses can be supported by data from different disciplines included in the SES framework. Arrows represent exit from investigation after sufficient support for a hypothesis towards understanding of interactions and outcomes of the system. After DeSalle et al. (2005).