A Framework for Rapid Assessment of Wildlife Markets in the Asia-Pacific Region for Relative Risk of Future Zoonotic Disease Outbreaks

Eric Wikramanayake[1*], David Olson[1], Dirk Pfeiffer[2], Ioannis Magouras[2], Anne Conan[2], Stefan Ziegler[3], Timothy C. Bonebrake[4]

[1] WWF Asia-Pacific Counter-Illegal Wildlife Trade Hub (IWT Hub), WWF-Hong Kong, 15/F, Manhattan Centre, 8 Kwai Cheong Road, Kwai Chung, New Territories, Hong Kong SAR, PR China

[2] Centre for Applied One Health Research and Policy Advice, City University of Hong Kong, Kowloon, Hong Kong SAR, PR China

[3] WWF-Germany, Kaiserstr. 70, 60329 Frankfurt/Main, Germany

[4] Division of Ecology & Biodiversity, School of Biological Sciences, The University of Hong Kong, Hong Kong SAR, PR China

* Corresponding author

E-mail: ericw@wwf.org.hk

Abstract

Decades of warnings by conservationists, epidemiologists, and virologists that the trade and consumption of wildlife could result in serious zoonotic pandemics have gone largely unheeded. Now the world is ravaged by COVID-19 that has caused tremendous loss of life and economic and societal disruption, with dire predictions of more destructive and frequent pandemics. There are now calls to tightly regulate and even enact complete wildlife trade bans, while others call for more nuanced approaches since many rural people rely on wildlife for sustenance. Given forces of political and societal expediency and limitations to enforcing bans, a response closer to the latter is more likely to unfold. But this will require monitoring and assessing trade situations for zoonotic risks. We present a framework for government authorities in the public health and wildlife sectors to assess wildlife trade situations for risks of serious zoonoses in order to inform policies to curtail or control the trade, much of which is illegal in most countries. The framework is based on available knowledge of different wildlife taxa traded in the Asia-Pacific Region, taxa known to carry highly virulent and transmissible viruses, and broad categories of market types and trade chains.

Introduction

Over the past two decades, conservationists, epidemiologists, and virologists have warned that the trade and consumption of wildlife could result in zoonotic disease outbreaks with potential to cause epidemics and pandemics [1-7]. Despite the clear evidence linking wildlife trade and consumption to zoonotic events [8-11], warnings to desist have been widely ignored and now the world is faced with a highly contagious and dangerous zoonotic virus, SARS-CoV-2-19, that has caused tremendous loss of life and economic and societal disruption, challenging and overwhelming the best of health services and systems on offer.

Of particular concern for zoonotic diseases outbreaks are the tropics where there is an increase in risk of disease emergence with higher mammalian species richness [12]. As the juggernaut of tropical forest conversion continues to increase contact between wildlife and humans and their livestock, the risk of exposure to novel pathogens and potential for spread will increase, especially as expanding road networks facilitate access and promote market opportunities and trade chains for wildlife [4,13-19]. Thus, urgent steps are needed to address the wildlife trade and wanton degradation of ecosystems.

With the COVID-19 pandemic raging across the world, there have been calls to tightly control and, in some cases, completely stop the wildlife trade [8,20]. China, argueably the biggest consumer and trading nation in wildlife, imposed a ban on terrestrial vertebrate wildlife consumption and trade, albeit with some loopholes [21]. However, there is also opposition to trade bans citing loss of livelihood opportunities, reduced access to food for local communities, and the possibility that the trade will be driven even more underground [22-26]. In time, it is more likely that a more nuanced approach will be the final outcome to address the nexus between wildlife consumption and reducing disease risks, since many rural people still hunt wildlife for food [27,28].

While most trade in wildlife has zoonotic risks, some currently traded taxonomic groups, such as primates, bats, pangolins, civets, mustelids, and some rodents are considered to be higher disease risk and should be kept out of markets [4]. Felids and canids are also known to be susceptible to viruses including SARS-CoV-2 (COVID-19) [29,30]. Furthermore, the removal of these predators from their natural ecosystems can increase the risk of of emerging infectious diseases, with ecological release of higher disease risk taxa, such as rodents [31-33].

The type of market situation or trade chain can also increase risk of disease transmission and spread. This can be based on several factors that include the numbers and types of taxonomic groups of wildlife being traded or transported, the diversity of animals for sale in a market, turnover of wildlife, the number of interactions between wildlife and people and domestic or peridomestic species, the length of trade chains, stressors on captive animals, and movement patterns of buyers and traders beyond points of sale [34].

Given that even rare zoonotic events associated with the wildlife trade can have catastrophic consequences for society, wildlife trade bans may be the only realistic approach to largely eliminate the risk of future trade-related pandemics. But societal pushback on wildlife trade bans may drive the application of more nuanced approaches that assess the risk level of markets based on the wildlife taxa being traded and the type of market or trade chain.

Here, we present a framework (S1 Appendix 1) to assess wildlife markets and trade situations in the Asia-Pacific region for risks of future zoonotic outbreaks based on the types of disease-risk taxa being sold and different trade situations. The framework is intended to provide guidance to the region's governments, especially the public health and wildlife sector authorities to assess the relative risk of potential new incidents of serious emerging infectious diseases associated with the trade in wildlife, and to help design appropriate policies to curtail and control the wildlife trade, much of which is illegal in most countries. The framework can also be used by other stakeholders, including non-governmental organizations, community-based organizations, and others to monitor markets for risks associated with wildlife trade.

Methods

The framework is based on available knowledge of different wildlife taxa that are: 1) sourced and traded in the Asia-Pacific Region and known to carry highly virulent and transmissible viruses; and 2) broad categories of market types and trade chains in the trade. Detailed descriptions about the use of the framework and the embedded formulae are presented in S2 Appendix 2.

Caveats

The framework can be improved with additional research and knowledge. Zoonotic and wildlife trade science is an evolving field. As more information is gathered it will improve our knowledge about viruses and other pathogens, primary and intermediate [35] wildlife hosts, and the role of wildlife trade chains in zoonoses. The new knowledge can then be used to test assumptions and improve judgements, including the parameters used in this framework. In the meantime, given the urgency to assess wildlife markets and prevent another pandemic, the framework can be applied invoking the precautionary principle. Lack of action is, and has been, simply too costly and unacceptable. We have also attempted to strike a balance in the framework between keeping it simple, transparent, and adaptable to improve it as more knowledge becomes available, but to also include enough key variables to make it sufficiently accurate and useful.

Market Trade Risk

Based on expert opinion solicited from WWF staff in the Greater Mekong Program and our own observations, we defined 11 different generalized trade situations in the Asia-Pacific region (Table 1). Some countries or regions may have a subset or variations of these types of trade chains.

General types of wildlife markets and points of sale are assessed for risk based on three variables: Transmission Risk (TR), Spread Potential (SP), and Zoonotic Virus Risk (ZVR). The assessment process and definitions of the risk variables are provided in Appendices 1 and 2, respectively. These three variables adequately classify the risks of potential zoonoses based on market size, crowding of wildlife that create stressful situations, hygiene conditions, number and turnover of people through the market (a proxy for the number of close interactions with wildlife), distance buyers may travel with wildlife purchases, and point along market trade chains that could allow viruses to accumulate and amplify the potential for zoonoses.

Each market type was given a qualitative score from 1-10, representing the combined contributions of the three variables (S1 Appendix 1). We also requested independent scoring of the variables to record the levels of uncertainty in assigning values to the three market variables. The scores were used to obtain a combined 'Market Risk' score with <1 = Lowest Risk; 1-2 = Low Risk; 3-5 = Medium Risk; 6-8 = High Risk; and 9-10 = Very High Risk (S1 Appendix 1, S2 Appendi 2).

Uncertainty in risk assessments can arise from a lack of information, data, or knowledge or from high variation inherent to a process or interaction in question. It is important to clearly convey the level of uncertainty when assigning relative risk attributes to different features or processes in a wildlife trade chain. We apply levels of uncertainty to our estimates of TR, SP, and VZR for assessing the risk associated with different wildlife trade and sales (S2 Appendix 2).

We assume that improvements in trade hygiene, regulation, and sale and butchering practices could diminish risk to some extent, but the distastrous socio-economic and health consequences of even one zoonotic disease pandemic event associated with trading in high disease risk wildlife argues for a broader set of actions. If high-disease risk taxa are being traded, no matter how clean the cages and knives are, dangerous viruses can jump to humans in trade chains.

High Disease-Risk Taxa

The assessment and scoring of taxonomic groups commonly traded in the Asia-Pacific region for hosting highly pathogenic visuses (Table 2) is provided in 'High Risk Taxa' worksheet Appendices 1 and 3. The risk categorizations of the taxonomic groups are presented in Table 3. We note that some taxonomic groups, such as rodents, are highly diverse and are likely to include species that may be of lower risk than others. However, given the severity of economic, health, and social costs and consequences of epidemics and pandemics and current gaps in knowledge about which species host which pathogens, we employ a precautionary principle and consider the taxonomic groups to be high disease risk until more information is available. We hope that this precautionary approach will encourage and catalyze additional epidemiological and zoonoses research to de-list or up-list species or taxa, as relevant and appropriate. As the status of these species change, the model can also be adjusted. We use simple, transparent, arithmetic formulas to enable these adjustments.

Evaluating Risk of Specific Markets or Points of Sale: Traded Taxa Risk

Taxonomic Risk Categories are then combined with a qualitative index based on the numbers of individuals from the respective taxonomic categories found in a market, the premise being that more animals can amplify the prevalence of pathogens and risk of transmission (see S1 Appendix 1 and S2 Appendix 2). For example, bats, including Pteropodidae, are known to carry a diverse suite of serious pathogens [19, 36-38]. If the estimated number of these Pteropid bats in a market is 1-3 individuals, the score would be Medium Risk, whereas if the numbers are >3, it would be classified as High Risk. But any number of bats in a market would pose at least a medium risk.

When using the framework, for a specific wildlife market, the numbers of animals for sale should be estimated—or counted, if few—and the data entered in the relevant column (S2 Appendix 2). These numbers are converted into qualitative threat categories via programmed formulas. Information on traded taxa and numbers of animals of each taxon can be derived from snapshot surveys or estimates from site visits over a day or longer period, or even be based on expert assessments. Finally, in the taxa risk assessment, the Taxonomic Risk category and Number-based Category are combined for a Cumulative Risk Factor using the matrix (Fig 1).

Combining Market and Taxon Risks

Market and taxon risk assessments are combined in a matrix of risks from the traded taxa (Y axis) and the respective markets or points of sale (X axis) (S1 Appendix 1; Fig 2) that provides an assessment of disease risk associated with a specific wildlife market. Risk levels for a given location may vary over time as different combinations and numbers of taxa are traded, but we assume, on average, that a similar set of taxa and numbers of animals traded will occur regularly in any given venue. Improvements in hygiene, regulation, and sale and butchering practices could, however, diminish risk, and in this context the tool can be used to monitor markets.

Ecohealth and Wildlife Trade

Deforestation, fragmentation, degradation, and settlement in tropical forests have been identified as significant drivers of emerging infectious diseases [15,39-42]. New roads bring in loggers, hunters, and settlers who may be exposed to novel zoonotic pathogens [4]. Wildlife taken from such areas for the commercial trade can also introduce novel pathogens into human populations [3,4,43]. The decline or loss of ecologically important species through deforestation and hunting degrades ecosystems and creates conditions that elevate risks of zoonotic events that typically accompanies deforestation [4]. Thus, trade in such species should end to prevent potential zoonotics, and the risk categorizations based on animals in markets reflect this by accounting for the ecological role of the species and their conservation vulnerability to trade (S1 Appendix 1). We emphasized the loss of top predators, major seed dispersers, and landscape engineer species in weightings.

Testing the framework

The framework was tested using survey data from 38 wildlife market and roadside stalls in Lao PDR [34, S3 Appendix 3]. Four market types were tested: permanent wildlife markets in larger cities (5 localities); regular wildlife markets in smaller towns (12); wildlife markets in villages (10); and roadside stalls (10). We only tested days where four or more wildlife entries were made. Where kilograms were entered instead of numbers of individuals for large animals, we entered one individual. We also tested data from eight wildlife trade sales from northern Myanmar, provided by WWF Myanmar from 2019 and 2020 (S3 Appendix 3).

Results

Each market type had days where disease risk was estimated as very low risk (VLR), low risk (LR), high risk (HR), and very high risk (VHR) (Table 4). The smaller town markets consistently had very high-risk days with little variation. This may be because these markets tend to be concentration points for high disease risk taxa brought in from surrounding villages. Markets in larger urban centers generally had medium risk levels or above, with some consistently estimated as very high risk, driven, in part, by high numbers of bats, wild birds, rodents, viverids, and other high-risk taxa.
The risk levels of village markets and roadside sales showed considerable daily variation, depending on the presence or absence of high disease risk taxa. These markets often had high disease risk species, such as bats, not commonly seen in the larger urban markets. The taxa for sale on any given day in these markets depends on what hunters bring in. Thus, one day there may be only squirrels and another day many bats and civets and disease risk will shift from low to very high. A precautionary approach would argue that disease risk levels for a given market locality should be assessed by averaging risk levels over multiple days and seasons. If this was done it is likely that most markets would have very high-risk days regularly or occasionally, though some village markets were consistently very low risk, perhaps due to wildlife depletion in the surrounding areas.

In Myanmar, the single warehouse sale (a trader's house) was very high risk because of the presence of langur and pangolin, while the restaurant sales at two venues were medium risk and very low risk, and a town market was very low risk because only reptiles were observed for sale on that day. Of the four roadside stall sites, three were very low risk and one was high risk. Some markets that were not tested had predominately dried animal parts, but these included endangered species such as tiger, gaur, and elephant skin or ivory. While these are illegal and very high conservation value species, the risk from zoonosis was low.

One clear trend from the model test is that smaller town markets consistently have very high disease risks. Another is that village and roadside sale venues regularly have very high disease risk situations. These disease risks should be evaluated with the knowledge that wildlife that remains for long periods in multiple-step trade chains and end up in crowded markets visited by many people may acquire higher viral loads and confer higher risk. The consistently high risk of the town markets may reflect a situation where many increasingly stressed high disease risk taxa are concentrated around many people, thus making these markets disease risk hotspots.

Another clear trend is that for all market types, there were high disease risk situations on different days depending on the numbers of the taxa being traded. Thus, most often for common wildlife trade situations in Southeast Asia there is regular to sporadic very high to high disease risk situations in the four market types, indicating that almost all unregulated wildlife trade has some disease risk.

Overall, the framework was able to discriminate variation among market types, localities, and risks on different days within individual markets. It also discerned general trends that can guide decision-making of health and wildlife authorities. In general, the model performed well with the data used to test it in that the results appear reasonable and consistent with expectations of disease risk, but we acknowledge that further testing can improve it.

Discussion

COVID-19 response: Calls for bans and systemic policies

The COVID-19 pandemic has elicited serious reevaluations of the consequences of trading in wildlife. China, the largest market for wildlife, imposed a blanket ban on terrestrial vertebrate wildlife markets and wildlife consumption [28]. Vietnam, another significant market for consumption and a conduit for wildlife to China, followed suit with a Prime Ministerial directive for tighter wildlife laws pertaining to trade and consumption of wildlife [27], but stopped short of a ban [44]. The effectiveness of these actions, however, remains uncertain. There are anecdotal reports of wildlife markets reopening or continuing to operate. Monitoring the vast numbers of markets in China can be an impossible task for government authorities. Much of the wildlife traded and consumed in China is sourced from other countries in Asia, especially the Greater Mekong Subregion through trade chains. Thus, the regional countries should also take steps to ban or tightly regulate the wildlife trade and monitor markets from rural sources through the urban markets and along the international trade chains for high disease risk and endangered wildlife.

Because pandemics from emerging zoonotics even more severe than the current COVID-19 are expected to become more frequent if current rates of forest encroachment, wildlife exploitation, and environmental degradation continue [15,45] there is a dire and urgent need for systemic policies on wildlife trade, under-written by science, to tackle such eventualities [13]. Millions of people in Asia still rely on wildlife sourced from forests. Thus, wildlife trade regulations that allow some hunting and local consumption should include evaluations of disease risks. The framework we present can help to assess the wildlife trade situations, from rural village trade stalls to urban markets, and various situations in between, for zoonosis risk and inform policy and help to monitor the relative zoonotic risks. Public health authorities can make decisions to ban or permit trade depending on the types and numbers of taxa being sold in these market situations and based on the estimated risks. Because the tool provides relative risk levels along various market types that would form links along a trade chain, the health and enforcement authorities can also make decisions about where along the trade chain relevant decisions can be taken, and where to enact enforcement for more effective and strategic action. For instance, if large urban markets are being supplied with high zoonotic disease risk taxa, such as primates or bats from rural markets, there may be more strategic opportunities to close the rural markets that sell these species or work with local communities to apprise them of the risks of hunting and trading in these species. Such strategic actions will require regional collaboration because the source markets may occur in other regional countries.

Even at national scales, bans and tighter regulations in wildlife markets would call for close monitoring of markets, including wildlife markets where some trade of low disease risk wildlife would be permitted. However, it is unlikely that governments would have adequate resources to monitor markets, especially in rural areas [28]. Our test of the tool with data from Laos shows that even rural and roadside stalls can carry high disease risk wildlife for sale. Thus, it is important that market monitoring engages non-governmental stakeholders, including from the public [28]. Such citizen scientists should have ready access to information and a tool that is easy to use and understand, and be practical enough, yet provide a robust assessment of the market conditions to detect and report illegal cases. The tool we present here meets these criteria. We acknowledge that it can be improved and refined, but such improvement can come from its use.

One Health approach for a holistic strategy

OneHealth, is a multisectoral, transdisciplinary approach that recognizes the connections among environmental, animal, and human health [43,46-48]. It is applied at scales from local to global to ensure environmental, animal, and human health, recognizing the inter-connectedness between people, Nature, and their shared environment. Ecosystem health is a core component of the OneHealth approach. Forest fragmentation, degradation, and loss has been associated with emerging infectious zoonoses with potential to cause epidemics and pandemics [3,4,15,41,43,48,49]. Hunting for local consumption has been a long-time practice among rural communities that live in and around the forests. But recently, the practice has intensified and shifted to supply market demands, especially from China, where the appetite for exotic wildlife has created a huge demand fed by the region's wildlife, creating 'empty forests' across southeast Asia, bereft of wildlife because of intense hunting pressure [e.g., 50]. As ecological communities are degraded with the removal of predators and scavengers, populations of high disease-risk species can irrupt due to ecological release, increasing the risk of dangerous zoonotic events [32,33,51]. This framework considers the ecological implications and consequences of hunting and removing key species from the ecosystem.

Asia's forests have a range of felid and canid predators, and their populations are in decline because of hunting pressure. While these species do not carry as many zoonotic-potential viruses relative to the higher-risk species, such as rodents, they are known to carry some high-risk viruses (S1 Appendix 1). We have classified these as medium-risk species for epidemiological risk, but because of their ecological status in controlling populations of other higher-risk taxa, such as rodents, we consider markets that carry even small numbers of wild felids and canids should be classified as at least a medium risk to capture the ecological and epidemiological fallout from removing these species from the ecosystem.

While some small rural markets may have few wildlife in stock, they could be the sources for the larger markets further along wildlife trade chains, especially as roads facilitate access for commercial buyers into remote, rural areas. These purchases may then be consolidated along the trade chains, increasing zoonotic risk. Moreover, thousands of small markets can contribute to ecological degradation of forests, especially if the markets are sourcing ecologically important and rarer species, such as primates, bats, felids, canids, and some perrisodactlya. Thus, rural markets that carry even small numbers of these species should qualify as medium to very high risk. For example, in our classification, even one great ape in a rural market qualifies it as very high risk.

Overall, we present this framework to assess various wildlife market situations and wildlife trade chains for potential zoonotic episodes and inform policy decisions to regulate or close such trade situations based on an objective analysis. We have kept the model simple, practical, and transparent so it can be used by a range of stakeholders, from government health authorities to conservation staff to non-government workers and citizen scientists. We acknowledge that the model is not perfect, but it is based on the best available knowledge. Thus, we have provided access to the formulae used to assess risks so they can be adjusted and refined as new information becomes available. Given the predictions that humans are setting the stage for more serious pandemic-proportion zoonotic spillover, this tool provides a timely, transparent, practical stop-gap measure for decision-making using precautionary principles. We hope this framework will also catalyze necessary research to close knowledge gaps and improve it.

Acknowledgements

The development of this assessment framework benefitted from discussions with Christo Fabricius, Yoganand (Yogi), Margaret Kinnaird, Michel Masozera, Colman O'Criodan, the WWF Wildlife Trade Disease Risk Task Force and invited experts, and from recent research and publications of the World Organization for Animal Health (OIE) and the WWF Global Science team, among others. Discussions and contributions from these specialists do not necessarily imply their agreement with all or parts of the approach. We appreciate the contributions of WWF-Myanmar, WWF-Greater Mekong Program, WWF-Hong Kong, WWF-Japan, WWF-Laos, and WWF Asia-Pacific Region Counter Illegal Wildlife Trade Hub teams.

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Table 1. General types of Asia-Pacific wildlife sale markets or points of sale.

Description of Wildlife Trade Sale/Trade Chain Type	**Generalized Type Name**
Larger, permanent markets in cities with locally animals wild caught, possibly transported over distance or international, or captive bred, alive and dead	Permanent wildlife markets
Wildlife sales from restaurants	Restaurant sales
Wildlife sales retrieved from warehouse on demand	Warehouse sales
Wildlife sales from TCM stalls (usually dead, dried, frozen)	TCM stalls
Wildlife sales from online or offline ads – shipped or picked up or delivered	Online trade delivery
Roadside sale of recently caught wildlife	Roadside sales
Rural (village) bushmeat markets (locally-caught or transported within region – live, dead, smoked, regular markets)	Rural bushmeat markets
Urban (town) bushmeat markets (domestic markets, town markets, caught in region, shorter transport)	Urban (town) bushmeat markets
Research animal facilities	Research facility
Local village sales/trade/barter & one-off sale from vehicles/boats of freshly caught wildlife	Local village sales/trade/barter
Wildlife farms (not evaluated)	Wildlife farms

Table 2. Virus families that have the potential to cause pandemics with severe public health and socio-economic consequences. All virus families included are RNA viruses with high genome plasticity (high error/mutation rate). The table does not include DNA viruses, which generally are highly adapted to their hosts through millions of years of co-evolution. Although some DNA viruses can also be zoonotic and even cause severe disease (e.g. Simian Herpes B, Monkey pox), there is no or limited human-to-human transmission in those cases.

Family	**Recent pandemics or epidemics**	**High case/ fatality**	**Pandemic potential with high consequence**
Coronaviridae	SARS, COVID-19 MERS	YES	**+++**
Orthomyxoviridae	Pandemic (2009) H1N1 H7N9 H5N1	YES	**++**
Paramyxoviridae	Nipah (Hendra)	YES	**++**
Retroviridae	HIV-1, HIV-2	YES	**+**
FIloviridae	Ebola, Marburg	YES	**+**

Note the following assumptions or criteria:

1. **Recent pandemics:** These are examples of viruses that have emerged in modern times and caused pandemics therefore these virus families are more likely to be involved again.
2. **Recent epidemics**: these viruses have caused or are still causing epidemics (localised outbreaks) and have the potential to evolve into pandemic strains especially if there are examples of pandemic viruses within the same family.
3. **High Case fatality:** Families include viruses that are associated with high case fatality ratios (>1%).

Other RNA virus families and why they are not included:

- *Rhabdoviridae*: humans are dead-end hosts and play no role in human-to-human transmission
- *Flaviviridae:* here specific vectors are involved in transmission and some viruses (Zika, Dengue, Chikungunya, West Nile) can cause severe epidemics but there are means of control, vaccines, seasonal occurrence etc. and have never resulted in lock-downs or other extraordinary measures as human-to-human transmission is negligible (e.g. blood transfusion)
- *Arenaviridae, Hantaviridae, Nairoviridae*: Mostly animal (and vector)-to-human dead-end transmission and limited evidence for human-to-human transmission.
- *Reoviridae* (rotavirus*)*: Generally, species-specific (some cross-species transmission evidence). Good vaccines available, fecal-oral transmission.

- *Hepeviridae* (Hepatitis E): Rare human-to-human transmission. Faecal-oral transmission can be controlled easily once sanitation improves therefore unlikely to spread globally.

Table 3. Taxonomic Risk categories of key faunal groups. Criteria for categorizations are provided in S1 Appendix 1.

Taxonomic Group	**Taxonomic Risk Category**
Primates-Great Apes (Orangutan, Gibbons)	High
Pteropodidae - fruit bats/flying foxes	High
Rhinolophidae - horseshoe bats	High
Sciurognathi - mice, rats, hamsters, jerboas, voles, others	High
Manidae - pangolins	High
Viverridae - civets, mongooses	High
Primates - monkeys, macaque, loris, tarsier, other non-great ape	High
Mustelidae - weasels, otter, badgers, hog badgers, polecats, marten	High
Wild birds - notably waterbirds	High
Sciuridae - squirrels	Medium
Suidae - wild pigs (e.g., Sus scrofa), babirusa	Medium
Cervidae, Moschidae, Tragulidae other deer-like Artiodactyla	Medium
Felidae - wild cats	Medium
Canidae - wild dogs, jackals, foxes, wolves,	Medium
Perissodactyla - tapir, rhinoceros, asses, horses	Medium
Ailuridae - red panda	Medium
Ursidae - bears	Medium
Hystricidae - porcupines	Medium
Tupaidae - tree shrews	Low
Elephantidae	Low
Dermoptera - colugo	Low
Leporidae - hares	Low
Reptiles	Low
Amphibians	Low
Fishes	Low
Invertebrates	Low

Table 4. Test of wildlife trade disease risk tool using field data from wildlife sale venues in Laos (Greatorex et al. 2016) and Myanmar (WWF Myanmar 2019-2020). Wildlife sales from Myanmar are designated with MM. Each cell is a single locality and multiple risk entries represent different days. Very High Risk = VHR; High Risk = HR; Medium Risk = MR; Low Risk = LR; Very Low Risk = VLR.

Large City Market	Town Market	Rural/Village Market	Roadside Sale	Trader or Warehouse	Restaurant
VHR VHR VHR	VHR VHR VHR VHR	VHR VHR VHR VHR VHR VHR MR LR	VHR VHR MR	VHR - MM	MR - MM (pangolin)
VHR	VHR VHR VHR	VHR VHR HR VLR	VHR LR LR		VLR - MM
VHR	VHR VHR VHR	VHR HR LR VLR	VHR		
HR	VHR VHR	VHR MR VLR	VHR		
M M M M	VHR VHR	VHR	VHR		
	VHR VHR	VHR	HR - MM		
	VHR LR	VHR	LR LR LR LR		
	VHR	MR VLR VLR	LR LR		
	VHR	VLR VLR VLR	LR		
	VHR	VLR	LR		
	LR		VLR - MM		
	VLR		VLR - MM		
	VLR - MM		VLR - MM		

	Taxa Risk			
Market Risk	**High Risk**	**Medium Risk**	**Low Risk**	**Lowest risk**
High Risk	Very High Risk	High Risk	Medium Risk	
Medium Risk	High Risk	Medium Risk	Low Risk	Low Risk
Low risk		Medium Risk	Low risk	Lowest Risk

Figure 1. Matrix of taxon risk categories used to derive the Cumulative Risk Factor

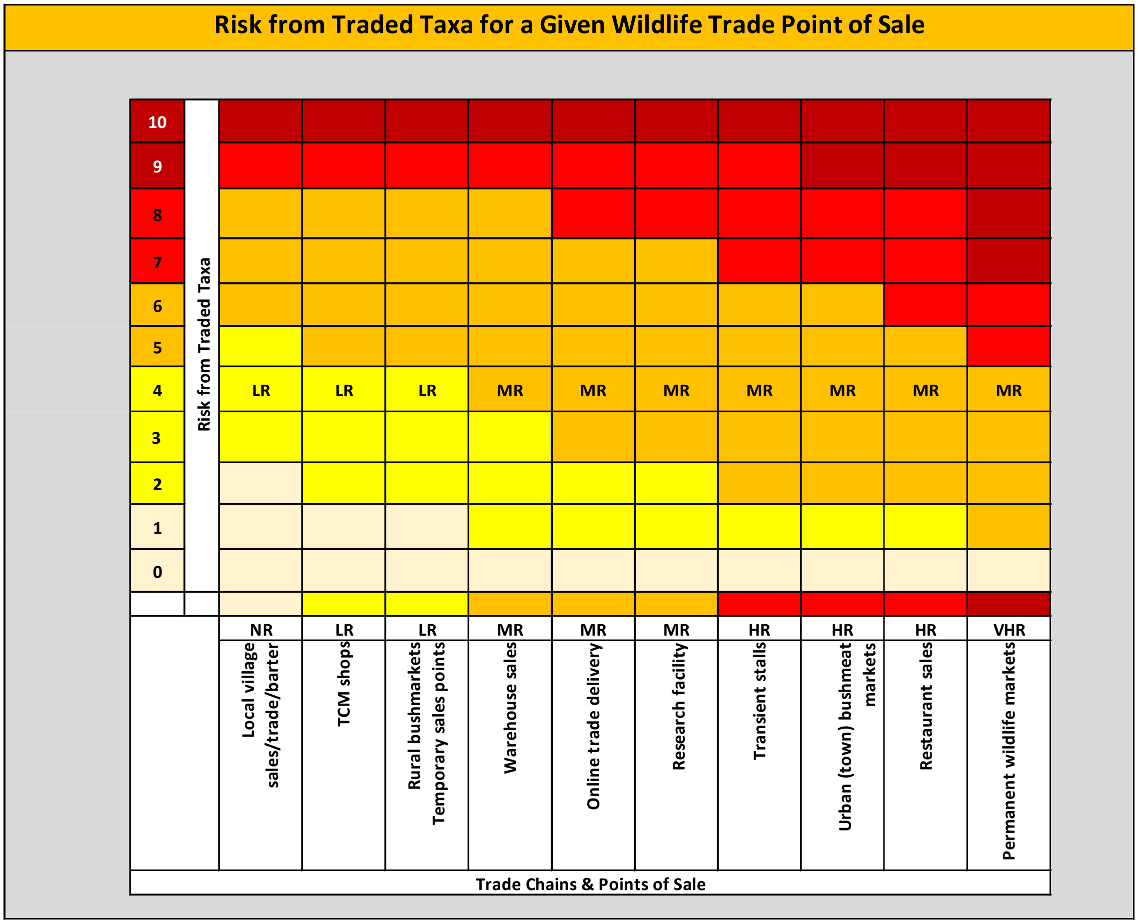

Figure 2. Graphic presentation of risks from traded taxa and trade chains (supplementary material Appendix 1). The VLR (beige cells), LR (yellow cells) and MR (orange cells) letters in this example estimate the trade situation as either low risk or medium risk for a combination of traded taxa and trade chain type. High Risk (HR, red) or Very High Risk (VHR, dark red) might be relevant for other combinations.