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A better classification of wet markets is key to safeguarding human health and biodiversity

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Wet markets have been implicated in multiple zoonotic outbreaks, including COVID-19. They are also a conduit for legal and illegal trade in wildlife, which threatens thousands of species. Yet wet markets supply food to millions of people around the world, and differ drastically in their physical composition, the goods they sell, and the subsequent risks they pose. As such, policy makers need to know how to target their actions to efficiently safeguard human health and biodiversity without depriving people of ready access to food. Here, we propose a taxonomy of wet markets, oriented around the presence of live or dead animals, and whether those animals are domesticated or wild (either captive-reared or wild-caught). We assess the dimensions and levels of risk that different types of wet markets pose to people and to biodiversity. We identify six key risk factors of wet markets that can affect human health: (1) presence of high disease-risk animal taxa, (2) presence of live animals, (3) hygiene conditions, (4) market size, (5) animal density and interspecies mixing, and (6) the length and breadth of animal supply chains. We also identify key factors informing risk to biodiversity. Finally, we recommend targeted, risk-adjusted policies to more efficiently and humanely address the dangers posed by wet markets.

Lancet Planet Health 2021; 5: e386–94

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Wet market controversy

In the wake of the COVID-19 pandemic and its possible origin at the Huanan Seafood Wholesale Market in Wuhan, China, attention has focused on the threats that wet markets pose to both human health and biodiversity.[1,2] The pandemic triggered calls for the permanent closure of all wet markets in China and elsewhere.[3] Such calls came from policy makers,[4] heads of influential governmental organisations,[5] non-profit organisations,[6] public health experts,[7] and even celebrities.[8]

A blanket condemnation of all wet markets presents at least three problems. First, imprecise language can foster xenophobia towards different cultures, especially with respect to long-standing and largely innocuous dietary practices.[9] Many wet markets sell only fresh produce and dead domesticated animals, and serve as the primary means of food acquisition and nutrition for a great number of people in the world, especially in east and southeast Asia.[10–14] When all types of wet markets are conflated and sensationalised as threats to human health,[15] anti-Asian sentiments can emerge.[16] Second, calls to ban all wet markets might be met by local or national resistance in countries where such markets abound, thereby blocking opportunities to target the types of wet markets that actually pose serious risks to people or biodiversity.[17] If sweeping bans on wet markets are nevertheless enforced, trade is likely to be driven underground, making conditions even harder to quantify, regulate, and reform.[18] Finally, such censure also presupposes that markets themselves are the root cause of global pandemics. Instead, markets vary in risk, and represent just one node of zoonotic transmission potential in animals and along the global wildlife trade supply chain. Solutions that do not differentiate between wet market types, or treat wet markets as the single modality from which pandemics might arise, ultimately could lead to unfeasible or ineffectual real-world policy decisions.[19]

In view of the impracticalities in closing all wet markets, calls for blanket wet market bans are being replaced by more targeted approaches. These approaches include

Key messages

Many wet markets do not sell live or wild animals
Wet markets are often incorrectly conflated with live-animal or wildlife markets. Wet markets sell consumption-oriented, perishable goods in a non-supermarket setting. By contrast, wildlife markets sell non-domesticated wild animals, either captive-bred or wild-caught, dead or alive. Live-animal markets sell live animals. The Huanan Seafood Wholesale Market in Wuhan, China, a possible source of the COVID-19 pandemic, was a wet market, live-animal market, and wildlife market.

Wet markets pose variable risks to human health and biodiversity
Wet markets comprise a broad class of markets that can affect human health and biodiversity to varying degrees. Risks to human health, in the context of emerging infectious diseases, include: the presence of high disease-risk taxa, the presence of live animals, unhygienic conditions, larger (and denser) markets, increased interspecies mixing and animal densities, and multiorigin sourcing and lengthy supply chains. Direct risks to biodiversity include the sale of threatened or declining wild-animal species.

Wet markets selling wild animals pose disproportionately large risks to people and biodiversity, especially if the animals are alive
Numerous wet markets around the world sell only dead, domesticated animals (eg, poultry). A smaller number of wet markets sell live, domesticated animals. Fewer still sell wild animals, dead or alive, alongside live or dead domesticated animals. Those markets selling live animals can pose large risks to human health and biodiversity, especially if they are selling live, wild animals, as evidenced by their disproportionate history of affiliated zoonoses.

Policy makers should prioritise addressing the riskiest types of wet markets, and future research should seek to better quantify those risks
Because wet markets are crucial to the lives of numerous people worldwide, policies should focus on minimising harmful disruptions to communities while best mitigating future health and biodiversity risks. Importantly, wet markets are not solely responsible for global pandemics; rather, they represent one node of zoonotic transmission potential along the global wildlife trade supply chain. Future research to quantify the risk factors posed by wet markets will enable decision makers to develop more effective and humane strategies to safeguard human health and biodiversity.

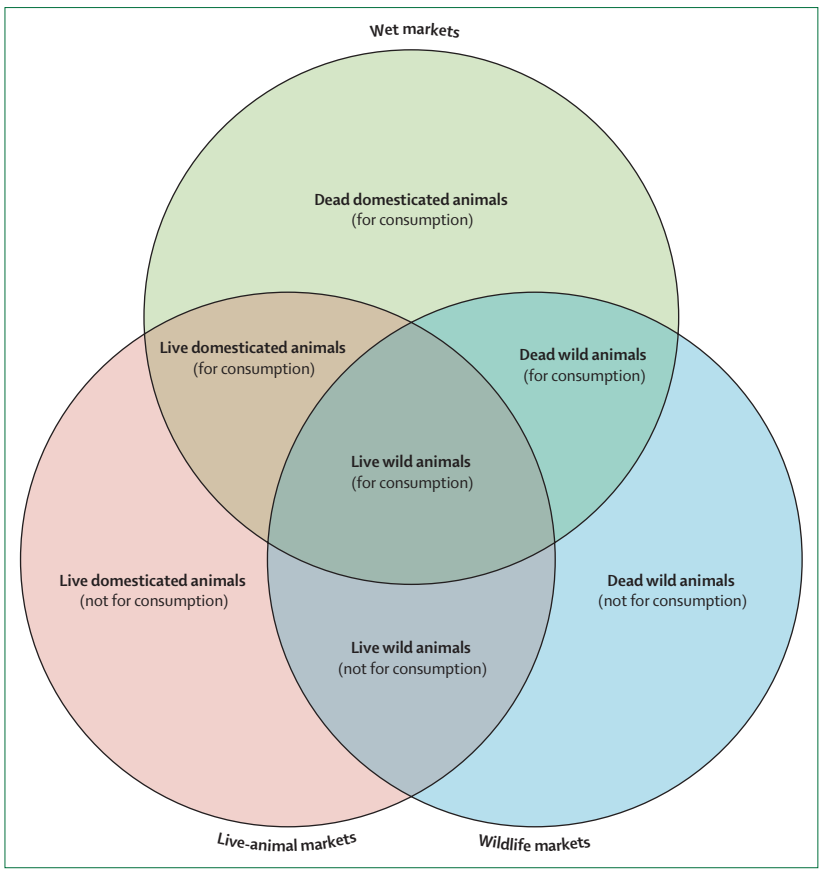

Figure 1: **Wet markets, live-animal markets, and wildlife markets**
Markets are separated on three dimensions on the basis of the condition, type, and intended usage of its animals: alive versus dead, domesticated versus wild, and consumption-oriented versus not consumption-oriented.

closing supposed high-risk wildlife markets,[20] improving market biosecurity measures,[21] and calls to end the commercial trade of wild animals for consumption.[19] All of these solutions would stand to benefit from a clearer classification of the different types of wet markets that exist, and the differential risks they pose. The Chinese Government has responded with alacrity to the COVID-19 crisis by banning the commercial sale and consumption of most terrestrial wildlife in China.[22] However, precedents of policy rollbacks,[23] deep-rooted cultural predilections favouring the consumption of wild animals,[24,25] and abiding zoonotic risks from domesticated animals, point to the value of having a way to rank the relative risks to human health and biodiversity of different types of wet markets, both in China and in countries without widescale wildlife-consumption bans in effect. Here, we propose a typology of wet markets to better delineate risks in existing market structures, and we provide a qualitative risk assessment for use by policy makers.

What are wet markets?

The term wet market has been used for decades to describe a broad class of markets that has existed for centuries. They were originally named after their frequently wet floors, a result of regular washing to keep stalls clean, plus the melting of the ice used to keep foods fresh.[26] In countries in east and southeast Asia, such as China, Taiwan, Thailand, Indonesia, Vietnam, Singapore, and the Philippines, wet markets often comprise rows of individual vendor stalls offering consumption-oriented, perishable goods (ie, fresh meats and produce), in an open-air or partially open-air setting.[27]

Thus, the term wet market can denote markets ranging from those selling just fruits and vegetables, to those selling wild-caught (and possibly endangered) wildlife for consumption. For effective policy formulation, it is essential to recognise critical distinctions among these types of markets, as their associated risks also differ. Wet markets sell consumption-oriented, perishable goods in a non-supermarket setting. Wildlife markets sell non-domesticated wild animals, alive or dead, captive-bred or wild-caught. Live-animal markets sell live animals. Accordingly, some wildlife and live-animal markets are indeed wet markets, whereas others are not (figure 1). The Huanan Seafood Wholesale Market in Wuhan, China, for instance, was a wildlife market, a live-animal market, and a wet market, selling an array of live and dead domesticated animals alongside non-domesticated species such as bamboo rats (*Rhizomys sinensis*), palm civets (*Paguma larvata*), badgers (family Mustelidae), and wolf cubs (*Canis lupus*) for consumption.[28] Conversely, the Barito, Jatinegara, and Pramuka bird markets in Jakarta, Indonesia, are live-animal and wildlife markets but not wet markets; these markets sell live birds and other animals for use as pets, but not as food.[29] Similarly, the famous Dried Seafood Market on Des Voeux Road West in Hong Kong sells foods and medicines, but virtually all of its items are non-perishable, thereby excluding it as a wet market (figure 2).[30]

Wet market risks

Risk encompasses both the likelihood of an undesirable event occurring and the repercussive severity of such an event were it to occur. Humans might have higher exposure to pathogens in domesticated animals, for example, which can result in repeated zoonotic infections.[31] By contrast, people might have lower exposure to pathogens in wild animals, yet that exposure can nonetheless trigger major disease outbreaks (eg, severe acute respiratory syndrome [SARS], Ebola virus disease, monkeypox, Nipah virus, and COVID-19, all of which probably trace their provenance to markets, farms, or pet stores selling wild animals). As such, risk is important but difficult to quantify and compare within categories of wet markets. Different risks can interact with one another, but assuming that they compound cumulatively (although not necessarily linearly), markets can be ranked according to their aggregate risks and be appropriately identified as more or less deserving of immediate attention from health or conservation officials. In this paper, we focus on the

risks of wet markets to human health and biodiversity loss, as these are well represented by specific market characteristics, and are both increasingly exigent and important to address given the strong possibility of future pandemics and the magnitude of the wildlife trade.[32]

Risks to human health

Many factors elevate a wet market's risk potential to human health. Here we focus primarily on factors associated with emerging infectious diseases (EIDs), due to the scale and cost of such events.[33,34] In general, the building blocks of an EID event (the emergence of a novel infectious disease in humans) consist of interspecific zoonotic transmission, viral amplification, and viral modification.[33,35,36] In this section, we identify six key characteristics of wet markets that can induce or facilitate such risks: high disease-risk taxa, live animals, hygiene, market size, animal density and interspecies mixing, and supply-chain length and breadth.

High disease-risk taxa

Certain taxa sold at wet markets might pose a greater risk to human health than others. A species' phylogenetic relatedness to humans has an important role in determining its potential for zoonotic spillover. In general, the more phylogenetically related a species is to humans, the more likely that diseases affecting that species can adapt to human hosts.[37] Empirically, this could be why most EIDs in humans have a mammalian origin.[38]

A species' disease risk to humans can also be correlated with the richness of that species' taxonomic order, its global abundance, and its inherent likelihood of harbouring zoonotic pathogens.[39–41] Taken together, rodents (order Rodentia), bats (Chiroptera), primates, carnivores (Carnivora), and ungulates (primarily Artiodactyla) might all exhibit elevated zoonotic potential within mammals. Apart from some ungulate species, most of the individuals from these orders found in wet markets are from non-domesticated species, some of which are wild-caught, others of which are captive-bred. Recently, the utility of using intrinsic species-specific characteristics to predict zoonotic risk has been challenged, suggesting that a focus on species canonically considered to be of high disease-risk in wet markets and elsewhere might not be as useful as once believed.[42] Pending further research that confirms or refutes this challenge, we continue to recognise some taxonomic groups as being of higher disease-risk than others.

Irrespective of a host-neutral outlook on zoonotic risk, because wildlife pathogens have caused more than 40% of all EID events, over 70% of zoonotic EID events, and virtually all pandemics in recent years,[33] exposure to species not commonly in contact with humans is likely to elevate the potential severity of disease risks.[42,43] This is not to say that zoonoses from domesticated animals should be overlooked, as such zoonoses can be deadly.[31,38] Rather, as human populations come increasingly into contact with previously isolated populations of wildlife, a complex interplay of viral adaptation between wild species, domesticated species, and people, can facilitate the emergence of novel zoonotic diseases.[43,44] Through increased virulence, rapid spreading, and inadequate existing medical knowledge or treatment, these diseases can be uniquely harmful to humans.[45,46]

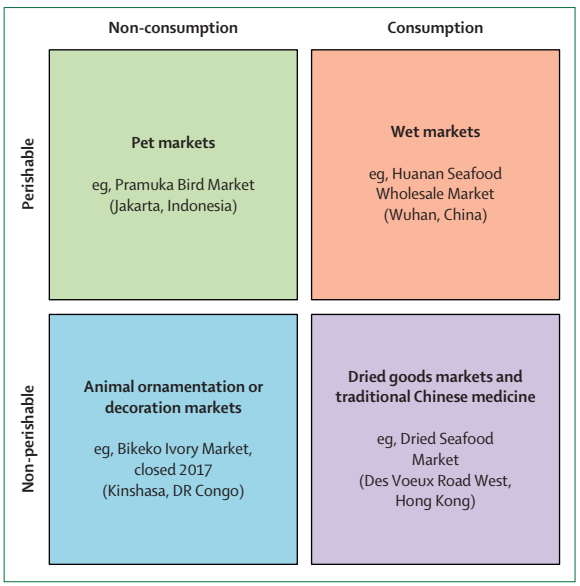

Figure 2: **Animal markets classified according to the types of goods sold**
Wet markets sell consumption-oriented, perishable goods, whereas other types of markets sell animals and animal products in other forms, oriented for other purposes.

We note that many publications highlighting the risks to human health from wildlife do not specify whether they are referring to wild-caught animals or captive-bred individuals of non-domesticated species (eg, farmed civets).[33,39,47] The degree to which wild-caught animals might pose a greater risk to human health from EIDs than do captive-bred, non-domesticated animals is uncertain and deserves additional research attention (we return to this distinction in our discussion of wet market risks to biodiversity).

Live animals

The presence of live animals in wet markets poses elevated risks of viral pathogen transmission. The interspecies and intraspecies mixing of live animals can facilitate pathogen shedding and viral recombinations in new hosts, which in turn can heighten the pathogenicity of animals to each other and to humans.[48] Heightened stress levels of captive animals (eg, due to high densities in confinement, new environments, or unfamiliar interspecies contact) can further compromise immune system responses and increase zoonotic disease transmission and virulence.[49,50] Exposure to live poultry in the marketplace, for instance, was a key risk factor in the viral spread of avian influenza during the 1997 H5N1 outbreak in Hong Kong.[51] This concern is even greater in markets harbouring wild animal

species, which often exhibit greater stress responses to transport or market conditions than do domesticated animals.[52]

Hygiene

Poor hygiene is a major risk factor for human health in wet markets, both through limited or unenforced biosecurity controls in markets themselves, and through hygiene risks magnified along lengthy supply chains of live animals. In wet markets without live animals, lapses in hygienic practices have been linked to bacterial and parasitic infections, often through the improper handling or storage of carcasses, polluted water, or proximity to other contaminants.[48,53] In wet markets with live animals, there is the additional risk of viral zoonoses, which can lead to EID outbreaks.[54,55] To mitigate risks, vendor handwashing, routine cleaning practices, and separation of different species can have positive health outcomes, whereas improper waste disposal and inadequate sanitation measures can exacerbate negative health outcomes.[56]

Market size

Market size can be defined in several ways (eg, trade volume, market spatial extent, or number of customers or transactions), but is generally related to the total number of people present and goods sold. As food handlers and marketgoers are often primary patients of zoonotic diseases, larger markets servicing larger numbers of people pose greater human health risks than do markets serving fewer people, given a constant density of vendor stalls and people. This is because larger markets increase the initial pool of susceptible hosts, along with their total exposure to pathogens, from both animals and each other.[48] In the SARS epidemic of 2003, around 40% of early patients were food handlers with probable animal contact; most of these patients lived closer to wet markets than to animal farms, suggesting that markets, not farms, were the initial source of transmission.[57] Animal handlers in these markets also had a considerably higher prevalence of SARS-CoV antibodies than did vegetable sellers in the same markets, corroborating this assertion.[58]

For **IUCN Red List** see https://www.iucnredlist.org

Animal density and interspecies mixing

The density of animal species within wet markets and along animal supply chains is important for viral disease transmission. Depending on a market's layout and the proximity of animals to each other, high animal densities can facilitate transmission of disease within animal species, between species, and between animals and humans.[59–61] Higher animal densities increase the likelihood of interspecies mixing and subsequent cross-contamination, which can lead to viral spillover, adaptation, and subsequent zoonotic disease emergence.[62–64] Such conditions, facilitated by a dearth of marketplace hygiene, were the hypothesised reason for the viral spillover of SARS from horseshoe bats (*Rhinolophus* sp) to civets (*Paguma larvata*) in 2003.[65]

Supply chain length and breadth

Because transport to end consumers frequently includes the close confinement of live animals, often under unhygienic conditions, lengthy supply chains can increase pathogen transmission and amplify disease risks. In a study of wild field rats (*Rattus* sp and *Bandicota* sp) in Vietnam, coronavirus presence was shown to increase along the supply chain, culminating in the highest levels at markets and restaurants.[66] Just as lengthy supply chains prolong the interspecies mixing of live, stressed animals, the multiorigin sourcing of animals (supply chain breadth) also elevates the potential for novel viral combinations.[56,67] This is especially relevant when wild species are introduced in unusual groupings with other wild or domesticated species, thereby facilitating unnatural viral spillovers.

Risks to biodiversity

The wildlife trade is a key contributor to global biodiversity loss, and affects one in every five vertebrate species, including many that are endangered.[32] In wet markets, the criteria for assessing biodiversity risks focus on which animal species are being sold, rather than on how such species are sold or on market conditions. Considered simply, wet markets that pose the greatest risk to biodiversity are those that serve as a conduit for the (often illegal) sale of threatened or declining wild species.

Threatened species are those with elevated extinction risks, according to their status on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (critically endangered, endangered, and vulnerable). Some of these species have been found for sale in wet markets, such as the Sulawesi fruit bat (*Acerodon celebensis*) in Indonesia, listed as vulnerable on the IUCN Red List;[68] the Bengal slow loris (*Nycticebus bengalensis*) in Laos, listed as endangered;[54] and the Sunda pangolin (*Manis javanica*) in Myanmar, listed as critically endangered.[69] Declining species include those that are not currently threatened (according to the Red List), but whose wild populations are declining rapidly enough to suggest they are approaching imperilment. These species can be recognised by other signals, such as population trend data provided by the IUCN Red List, increasing prices and declining sales volumes in markets,[70] their placement on national or subnational (ie, state or provincial) threatened-species lists, seizure data from the Convention on International Trade in Endangered Species of Wild Fauna and Flora, or as designated by various scientific authorities. BirdLife International, for example, estimates that at least 40% of the world's bird species are declining.[71]

Overall, the sale of domesticated animal species in wet markets poses little direct risk to biodiversity, but this is not the case for the sale of many wild species, either captive-reared or wild-caught. The distinction between wild-caught animals and captive-bred, non-domesticated animals is relevant here. Domestication is essentially a

sustained, multigenerational, mutualistic relationship between animals and humans, characterised by intentionality on the part of humans in the selection of particular traits in the species being domesticated.[72] This implies both a cultural and biological component to domestication, which complicates any simple binary classification. Each and every species cannot be tagged as either fully domesticated or fully wild. As such, we encourage recognition of three groupings of species: domesticated species that have undergone many generations of human-controlled reproduction (eg, poultry and cattle), non-domesticated but commonly captive-reared species (eg, farmed porcupines, pythons, and bamboo rats), and wild-caught species (eg, certain species of bats, monkeys, and pangolins).

The sale of wild-caught individuals of threatened or declining species presents a clear threat to biodiversity, as it directly contributes to species' extinction risk. Alternatively, the commercial farming of wild species (as distinct from the captive-breeding of threatened species solely for conservation purposes)[24,73] is sometimes presented as a way to sustainably produce threatened species for consumption.[74] However, biosecurity concerns, economic barriers to entry, and cultural predilections favouring wild-caught meat mean that wildlife farms have yet to replace other forms of wildlife acquisition (eg, hunting or poaching) in many markets.[75,76] Additionally, because wildlife farms can require periodic restocking from wild-caught specimens, their efficacy in aiding conservation efforts remains uncertain.[76,77] As such, the sale of threatened or declining species in wet markets, regardless of origin, should be grounds for biodiversity concern.

There is a relatively small number of species that are imperiled in the wild but abundant in captivity. For example, the American bison (*Bison bison*) is classified by the IUCN Red List as near-threatened,[78] despite also being raised commercially for its meat. Unless the commercial farming of such species facilitates laundering of illegally harvested individuals from wild populations,[79] the presence of such species in wet markets is not necessarily evidence of a risk to biodiversity.

Finally, it should be noted that risks to biodiversity are further elevated, indirectly, by habitat destruction and infrastructure that facilitates access to novel species. Habitat destruction imperils sensitive species that are not themselves directly extracted for sale and consumption.[80] Improved access to wildlife habitats also increases trade volumes of captured animals, and magnifies risks to human health.[81,82] It is also clear that demand for domesticated-animal products, in wet markets and elsewhere, helps to sustain the expanding livestock industry, a major driver of habitat loss.[83,84] Although such secondary risks are crucial to consider, they pertain to the entire livestock industry and meat consumption as a whole, and so are excluded from specific consideration here.

A risk framework across wet market types

By creating a taxonomy of different wet market types and classifying their relative risks to human health and biodiversity, we can better articulate where public health and conservation efforts should be directed most urgently. Although wet markets differ from market to market and instance to instance, we identify a progression of four broad wet market types:

1. Markets selling no live animals (excluding seafood) for consumption and only domesticated-animal products, alongside anything else (eg, fruits and vegetables)
2. Markets selling live domesticated animals for consumption, alongside anything else (possibly including dead domesticated-animal products)
3. Markets selling dead wild animals (either captive-reared or wild-caught) for consumption, alongside anything else (possibly including live domesticated animals, and dead domesticated-animal products)
4. Markets selling live wild animals (either captive-reared or wild-caught) for consumption, alongside anything else (possibly including dead wild animals, live domesticated animals, and dead domesticated-animal products).

In addition to outlining the risks these wet market types pose with regard to EIDs and biodiversity, we also qualitatively assign risk levels (low, medium, and high) from the seven identified health and biodiversity factors to each market type (figure 3).[33,48–58,61,63,66,85,86] As risk designations are subjective and interactive with other factors, this framework informs cumulative risks to human health and biodiversity of different wet market types, but does not enumerate individual risks viewed in isolation of other factors.

Wet markets with no live animals

This category probably constitutes most wet markets, and certainly constitutes the direction in which many wet markets in Asia are heading.[26,87–90] Relative to other market types, wet markets selling no live animals (and only dead domesticated-animal products) present the lowest risks to both human health and biodiversity. They pose no direct threat to biodiversity loss (although consequential biodiversity concerns associated with the livestock industry remain), as they contain no wild animals, and they have not been associated with the presence or propagation of any historical EID events. However, such markets are often informal and unregulated, thereby still presenting parasitic and bacterial foodborne health risks largely driven by inadequate hygiene practices.[53]

After banning the sale of live poultry in the 1990s and 2008, wet markets in Singapore and Taiwan, respectively, now all fall under this category (this excludes live seafood, which has historically had lower associated zoonotic risks relative to other types of animals).[26,87,91] As of July, 2020, China has also announced its plan to phase out all live poultry from its wet markets in response to the COVID-19

	Wet market types			
	(1)	(2)	(3)	(4)
	Dead domesticated animals, excluding live seafood	**Live domesticated animals**, including any of **(1)**	**Dead wild animals**, including any of **(1)** or **(2)**	**Live wild animals**, including any of **(1)**, **(2)**, or **(3)**
High disease-risk taxa present	**Low** No historical EID events have been linked to such markets	**Medium** Live domesticated animals in wet markets have been linked to past EID outbreaks such as avian influenza[48]	**High** Wild animals in wet markets can comprise high disease-risk taxa for EIDs[33]	**High** Same as (3)
Live animals present	**NA** No live animals sold in such markets	**Medium** Live animals facilitate viral shedding and zoonotic transmission;[48,63] stress increases live animals' susceptibility to infection[49,50]	**Medium** Same as (2)	**High** All of (2), and live wild animals can display greater stress responses to transport or market conditions than domesticated animals[52]
Poor hygiene	**Low** Poor hygiene elevates the risk of foodborne illnesses[53,55]	**High** Poor hygiene elevates the risk of zoonotic EID events[48]	**High** Same as (2)	**High** All of (2), and the presence of live, wild animals elevates the risk of EID events[48,54]
Large market size	**Low** No historical EID events have been linked to such markets	**Medium** Larger markets increase the pool of susceptible human and animal hosts to EID spillovers[51,57,58]	**High** All of (2), and wild and domesticated animals sold together elevates the risk of EID events[48]	**High** All of (3), and the presence of live, wild animals elevates the risk of EID events[33]
High animal density and interspecies mixing	**Medium** The tight confinement of live, domesticated animals along the supply chain can pose health risks[63]	**High** Interspecies contact facilitates viral spillover and amplification along the supply chain and at markets[61,63,85]	**High** All of (2), and the presence of high disease-risk taxa elevates the risk of EID events along the supply chain[33,86]	**High** All of (3), and the presence of high disease-risk taxa elevates the risk of EID events at markets
Long length and breadth of supply chain	**Medium** Lengthy supply chains can exacerbate hygiene issues and interspecies mixing;[66] multiorigin sourcing can facilitate viral spillover[56]	**Medium** Same as (1)	**High** All of (1), and wildlife supply chains can be lengthier or more irregular than those of domesticated animals and elevate the risk of EID events[66]	**High** Same as (3)
Threatened or declining species sold	**NA** No threatened or declining animal species sold in such markets	**NA** No threatened or declining animal species sold in such markets	**High** Wild animals in wet markets can be of threatened or declining species (see section entitled Risks to biodiversity)[54]	**High** Same as (3)

Figure 3: **A taxonomy of EID and biodiversity risk across wet market types**
EID=emerging infectious disease. NA=not applicable.

pandemic,[89] supplementing its earlier nationwide ban on the use of wildlife for food consumption (although not for medicine) in February, 2020.[90]

Wet markets with live domesticated animals

In this market type, live domesticated animals are present and slaughtered on customer demand. Such animals often consist of just poultry or seafood (eg, some wet markets in Hong Kong),[92] but other live domesticated animals can also be present. Although such markets present no direct threat to biodiversity, the presence of live (domesticated) animals escalates the human health repercussions of increased animal densities, interspecies mixing, long supply chains, multiorigin sourcing, and poor hygiene.[67] This elevates health risks to animal handlers and marketgoers at all points along the supply chain, as live animals are better channels for pathogen shedding and viral amplification than dead animals.[51,58,85] Short of permanently closing all such live-animal wet markets, periodic but temporary market closures for cleaning and disinfecting can decrease viral presence.[93,94]

Wet markets with dead wild animals

Such markets sell dead wild animals, either wild-caught or captive-bred, but can also include live or dead domesticated animals for sale. This and subsequent categories of wildlife wet markets are much rarer than wet markets selling just domesticated animals,[88] but the Tomohon Extreme Market in Sulawesi, Indonesia, is one such market, selling dead wild animals such as fruit bats (*Acerodon celebensis* and *Pteropus alecto*), snakes (*Python* sp), and wild pigs (*Sus celebensis*), alongside live and dead domesticated animals such as chickens, ducks, and dogs (as of February, 2019).[68] In addition to the risks posed by live domesticated animals in wet markets, the presence of dead wild animals presents additional health risks through the inclusion of more high disease-risk taxa, which increases the likelihood of novel pathogens and interspecific spillover, including to humans, along the supply chain. Importantly, such markets also present meaningful risks to biodiversity when threatened or declining wild species are sold. The Tomohon Extreme Market, for instance, has been known to source the critically endangered Celebes crested macaque (*Macaca nigra*), a banned but favoured delicacy of the local Minahasan community in Sulawesi.[68]

Wet markets with live wild animals

Such markets include the purported source of the SARS-CoV-2 outbreak, the Huanan Seafood Wholesale Market in Wuhan, China; this sold live and dead wildlife such as bamboo rats (*Rhizomys sinensis*) and badgers (Mustelidae) alongside live and dead domesticated animals.[28] Live animals facilitate zoonotic transmission, wild animals often comprise high disease-risk taxa, and live and wild animals together pose the greatest cumulative threat to human health of any wet market type. Even with proper hygiene and market practices, such markets' inherent risks to human health are difficult to mitigate. These markets also present unavoidable risks to biodiversity when the wild species sold are threatened or in decline.

Looking forward

Wet markets come in many shapes and sizes, are widespread throughout the world, and serve essential needs of numerous people. Some wet markets pose a

Search strategy and selection criteria

This Personal View draws from our reading of the medical and conservation peer-reviewed literature in English. Search terms used to find peer-reviewed articles in Google Scholar included a combination of: "wet market", "wildlife", "zoonosis", "emerging infectious disease", "wildlife trade", "live-animal market", and "wildlife market". No date restrictions were applied to the literature search; the last search was done on Dec 23, 2020. Contemporary news articles, drawn from both English and Chinese sources, were used to contextualise the public controversy surrounding wet markets. The studies cited are not exhaustive but were chosen in relation to their pertinence to wet markets, human health, or biodiversity, with a particular geographical focus towards east and southeast Asia.

substantial threat to human health and biodiversity, but by no means do all. Hence, a generic, overly broad treatment of wet markets to address concerns about EIDs or biodiversity loss lacks context, and is likely to face much resistance from both vendors and customers. A targeted approach might prove more effective, starting with a qualitative risk analysis that recognises the variety of wet markets in existence.

To assess risks to human health, we identify six key aspects of wet markets: (1) the presence of higher disease-risk taxa, (2) the presence of live animals, (3) hygiene conditions, (4) market size, (5) animal density and interspecies mixing, and (6) supply chain length and breadth. To establish risks to biodiversity, we identify threatened species by their extinction risk in the wild (represented by their IUCN Red List status), and declining species by metrics such as IUCN Red List population trend data, threatened-species lists, and changes in market prices and availability. These criteria are not exhaustive, but they allow us to begin to build a risk framework to identify which types of wet markets cumulatively engender the greatest threats to people and biodiversity. Future research can bolster this with quantifiable ways to assess, isolate, and compare risks across market types and risk dimensions.

The cumulative risks of different wet markets to both human health and biodiversity appear inversely proportional to their prevalence and popularity.[88] Most wet markets probably pose comparatively little risk to human health or biodiversity, but a few pose a disproportionately large risk. When classified on the basis of the presence or absence of live and wild animals, wet markets can be arranged along a nested progression of risks to human health and biodiversity, culminating in the proportionately small number of wet markets selling live, wild animals that have been the source of many previous EID outbreaks.

Looking forward, policy makers should prioritise regulating these markets and taking steps to prevent a resurgence of their most high-risk aspects (eg, bans on the trade of wild-caught vertebrates for consumption), before turning their attention to other types of wet markets that pose less risk to people or biodiversity. Doing so will minimise harmful disruptions to communities, while diminishing market-associated risks to health and biodiversity. If only in the narrow context of human health, channelling scarce national and international resources towards targeted reductions in zoonotic risk in wet markets and elsewhere can help circumvent the next global pandemic. In the context of biodiversity, targeting those markets that sell threatened or declining species, either alive or dead, can close a consequential outlet for unsustainable and often illegal wildlife trade. In the context of human, animal, and planetary wellbeing, realistic and effectively targeted reform is preferable to sweeping but ineffectual change.

Contributors

BL and DSW conceived of this project idea, BL and MLD wrote the first draft, and all authors contributed to subsequent drafts, revisions, and the final manuscript.

Declaration of interests

We declare no competing interests.

Acknowledgments

We thank four anonymous reviewers, Willandia Chaves, Alex Wiebe, Christopher Crawford, and the rest of the Wilcove Lab (the Drongos) for their helpful suggestions, and Ken Lin for Chinese language translations. We thank the High Meadows Foundation and Princeton University for ongoing support of the work of BL, RAS, and DSW. The World Wide Fund for Nature funded some of the research work of MLD.

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