An investigation into the wild meat trade in Malaysia and its implications for zoonotic disease

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Abstract

Hunting wildlife for food has detrimental effects on many wild animal populations and represents a major threat to biodiversity. The great diversity of zoonotic pathogens identified in wildlife hosts may pose infection risks to humans involved in the wild meat trade. Southeast Asia is a hotspot for zoonotic emerging infectious diseases and the commercialisation of this trade presents challenges to wildlife conservation and public health. This dissertation explores these issues in Malaysia to better understand the consequences of wildlife trade.

This study utilises survey data from establishments selling wild meat across Malaysia (collected by TRAFFIC Southeast Asia) in order to identify commonly traded species and uses published information to examine the drivers and impacts of this trade on wildlife populations. A literature review determines the potential zoonotic infection risks and transmission routes to hunters, traders and consumers, focusing the discussion on significant pathogens from commonly available species. The microbial food safety risks of this trade are highlighted by a proposal to conduct a risk assessment on the hazard of Shiga-toxin producing *Escherichia. coli* (STEC) from wild deer, following Codex Alimentarius Commission guidelines.

This dissertation suggests that consumer preferences for wild meat drive the increasingly commercial trade in Malaysia, with wild pig, deer and reptile species being commonly hunted and leading to significant impacts upon some populations. The great variety of traded wildlife can host numerous zoonotic pathogens and several species (e.g. wild ungulates, reptiles and macaques) may harbour multiple pathogens, which can cause human diseases associated with hunting, butchering and consumption. Many bacteria and parasites are transmitted to humans via foodborne routes, which lead to the proposal for a food safety risk assessment on the STEC hazard from wild venison. The review also highlights the lack of pathogen data for certain species and advises further epidemiological research on wildlife and human populations in Malaysia. Overall, the dissertation asserts that the wild meat trade threatens wildlife populations and risks human zoonotic disease in Malaysia, a conclusion of importance for conservation and public health strategies.

1. Introduction

Globally, one of the most significant threats to wildlife populations in tropical forests is the hunting of species for human consumption, which supplies the "bushmeat" or "wild meat" trade. This geographically widespread exploitation of wildlife is particularly intensive in the Amazon Basin (Peres, 2000), the Congo Basin (Fa et al., 2000; Poulsen et al., 2009) and Southeast Asia, including Indonesia (Luskin et al., 2014), the Philippines (Scheffers et al., 2012) and Malaysia (Bennett et al., 2000). Although historical records indicate that hunting mammals for food has occurred in Asian forests for at least 40,000 years (Corlett, 2007), the increase in wild meat consumption during recent decades now represents a major threat to biodiversity in the humid tropics (Milner-Gulland and Bennett, 2003).

The specific terminology used reflects variations in hunting legality and utilisation of meat. The "bushmeat trade" refers to the illegal hunting of wildlife often in unauthorized areas in order to supply meat for commercial trade, whereas "the wild meat trade" describes the hunting of wildlife by local hunters for subsistence and non-commercial purposes that may be legal (Eves, 2002). Both types of trade will be discussed in the dissertation, but the "wild meat trade" will be used as the general term unless otherwise specified. The discussion of "game meat" is not relevant to the dissertation as it describes regulated commercial operations for the legal exploitation of wildlife for meat (Eves, 2002).

Published literature has highlighted the massive scale of this trade. One study estimated that over 5 million tons of wild mammal meat were consumed by people in Neotropical and Afrotropical forests annually (Fa et al., 2002b) and the annual wild meat harvest in Sarawak, Malaysia, has been estimated at 23,500 tonnes (Bennett, 2002).

Several factors have contributed to over-hunting:

- Human population growth (Peres, 2000);
- Modern hunting technologies (Milner-Gulland and Bennett, 2003);

- Roads, agriculture and logging increasing accessibility to undisturbed forests (Peres, 2000; Poulsen et al., 2009);
- Improved connectivity between forests and markets (Robinson et al., 1999);
- Ineffective enforcement of conservation legislation (Wilkie et al., 2011);
- Commercialisation of the wildlife trade (Milner-Gulland and Clayton, 2002).

The anthropogenic threats of over-hunting combined with forest habitat loss have contributed to:

- Local extirpations e.g. of susceptible large-bodied vertebrates (Peres, 2000);
- Global extinctions e.g. *Procolobus badius waldroni* (Oates et al., 2000);
- Alterations to the dynamics of tropical forest ecosystems (Wright, 2003);
- A reduction in biodiversity leading to the creation of “empty forests" (Redford, 1992).

Furthermore, the wild meat trade may often contravene national legislation and international treaties, which undermine conservation efforts aiming to protect threatened species and/or populations of species. Unsustainable levels of commercial hunting may also have negative effects on the livelihoods of indigenous people in rural communities (Robinson and Bennett, 2002). Therefore, the complex ecological, socio-economic and legal consequences of this trade issue should be considered.

The social, cultural and economic drivers of the wild meat trade have been extensively investigated in Africa (Fa et al., 2002a; Wilkie et al., 2005) and Latin America (Nasi et al., 2011; Peres, 2000), but to a lesser extent in Southeast Asia. Wild meat can supply forest inhabitants with an important protein source to support subsistence living (Townsend, 2000), especially where poverty is a factor (Nasi et al., 2011) and its consumption may also be culturally important to some communities (Peres, 2000). In some regions, hunters may rely upon the sale of bushmeat to supplement household incomes e.g. Democratic Republic of Congo (de Merode et al., 2004), but the commercialisation of this trade can extend beyond rural areas to supply urban consumers (East et al., 2005).

Rural communities in Southeast Asia may have particular traditions of eating wild meat, but they are often less reliant on its protein value and can sell the excess, as highlighted by surveys in East Malaysia (Bennett et al., 2000) and the Philippines (Scheffers et al., 2012). Commercial hunting in Asia has increased due to professional hunters exploiting wildlife for financial gain (Milner-Gulland and Clayton, 2002) and wild meat may be valued by consumers for its luxury status or perceived health benefits (Corlett, 2007; Drury, 2011). Recent rapid economic growth and development in Southeast Asia has assisted this trade by opening up previously inaccessible wildlife habitats to external markets (TRAFFIC, 2008).

Research has suggested that the rise in zoonotic emerging infectious diseases (EIDs) is related to anthropogenic activities, e.g. the global wildlife trade (Karesh et al., 2007) and one literature review documented over 35 zoonotic diseases associated with wildlife trade and movement (Travis et al., 2011). Another study identified that 71.8% of EID events in humans were caused by zoonotic pathogens originating in wildlife (Jones et al., 2008), which implied contact with wildlife may pose significant health risks. Southeast Asia is considered to be a hotspot for EIDs (Coker et al., 2011) and this paper highlighted several examples, including the 2003 Severe Acute Respiratory Syndrome (SARS) outbreak that originated in China and spread through this region to cause 44 deaths in 5 countries.

The factors associated with an increased risk of EIDs in Southeast Asia include: the great diversity of zoonotic pathogens present here; the high density and close proximity of humans and animals enabling zoonotic transmission; and ecological shifts favouring disease emergence (Coker et al., 2011). The extensive distribution networks of the wildlife trade have facilitated cross-species transmission of pathogens, e.g. Asian wet markets (selling live animals and fresh food) enabled the spread of SARS-associated coronavirus from bats to civets to humans (Li et al., 2005c).

Each stage of the wild meat trade (hunting, carcass processing and consumption) risks human zoonotic disease from contact with live and dead animals. Zoonotic infections associated with bushmeat hunting have often occurred in Africa, including an Ebola disease outbreak in Central Africa that was related to the handling of infected chimpanzee, gorilla and duiker carcasses (Leroy et al., 2004) and the identification of human T-lymphotropic viruses types 3 and 4 in primate hunters from Cameroon (Wolfe et al., 2005). Foodborne infections from wild meat have also occurred, e.g. cases of Hepatitis E in Japan related to raw or undercooked wild boar and venison consumption (Matsuda et al., 2003; Tei et al., 2003).

There have been fewer reports from Southeast Asia of zoonotic infections in wildlife hunters and consumers compared to numerous cases documented in Europe (Garin-Bastuji et al., 2006; Halaby et al., 2000; Rodríguez et al., 2004) and North America (Giurgiutiu et al., 2009; Ross et al., 2001; Wilkins et al., 2008), where hunting is an important recreational industry. Some trichinellosis and sparganosis cases have been reported in Thailand due to wild pig and reptile meat consumption (Anantaphruti et al., 2011; Jongwutiwes et al., 1998; Khamboonruang, 1991) and pentastomiasis has been documented in Malaysian aborigines who ingested snake meat (Latif et al., 2011; Prathap et al., 1969). Recently, researchers screened exotic meat samples from across Malaysia for four zoonotic parasites and found *Sarcocystis* and *Toxoplasma gondii* in civet, squirrel, terrapin and monkey meat (Fazly et al., 2013), of concern for wild meat consumers. The lack of published data within Southeast Asia may reflect inadequate regional disease monitoring and surveillance that contributes to under-reporting of cases (Coker et al., 2011).

In 2012, the wildlife trade monitoring network, TRAFFIC Southeast Asia, commissioned a survey of wild meat establishments (restaurants, roadside stalls and markets) across Malaysia (Peninsular Malaysia, Sabah and Sarawak) that identified the numbers, variety, sources and legal status of wildlife species traded (Caillabet et al., Unpublished). The dissertation uses the data from this survey in combination with a literature review and risk assessment proposal to examine the zoonotic disease, public health and conservation implications of the wild meat trade in Malaysia.

The aims of this dissertation are:

- To utilise the data collected from the TRAFFIC survey to determine the most commonly available wildlife species traded for wild meat in Malaysia and discuss the drivers of this trade based upon published literature;
- To examine the impact of the wild meat trade upon identified species in relation to their conservation status and the level of hunting threat on wildlife populations in Malaysia;
- To perform a literature review to identify the potential zoonotic infection risks from wildlife species and the transmission routes to humans at each stage of the wild meat trade;
- To provide a discussion on the significant zoonotic pathogens from the most commonly traded wildlife species;
- To describe a proposal for a qualitative risk assessment on the microbial risks from STEC for wild deer consumers in Malaysia.

Dissertation Hypothesis: An improved understanding of the drivers and impacts of wildlife hunting in Malaysia combined with knowledge about wildlife-human zoonotic disease from global scientific research may be used to combat the increasing commercialisation of the wild meat trade within the country.

2. Analysis of TRAFFIC Report Data

2.1 Methodology

Data from an unpublished TRAFFIC report (Caillabet et al., Unpublished) was combined for analysis. This dataset contained the results of a six-month survey that investigated species availability in wild meat outlets located in Peninsular Malaysia, Sabah and Sarawak during 2012. The short time period for data collection will only have provided a “snapshot” of information about the trade.

The percentage of wild meat availability for each species traded in Malaysia[1] has been calculated from the number of establishments serving the species divided by the total number of establishments surveyed and is presented in Table 1. Some wild meat could not be identified to species level due to the difficulty in distinguishing between carcasses from similar species, accordingly this data is presented in animal groups, e.g. for deer, squirrels, civets, flying-foxes, porcupines and tortoises. The survey also regionally excluded wild meat from species in areas where they are farmed (e.g. softshell turtles from Peninsular Malaysia and estuarine crocodiles from Sabah) since it was considered to be “game meat” rather than “wild meat” (as defined in the introduction) and it would not have been possible to distinguish between farmed and wild-caught reptile meat. Consequently, this may have affected the overall results of national wild meat availability for these species, shown in Table 1.

[1] Malaysia refers to Peninsular Malaysia and East Malaysia (Sabah and Sarawak)

2.2 Results

Table 1 lists the taxa from which the wild meat was sourced and shows the percentage availability for each.

Table 1: Wild meat availability in surveyed establishments across Malaysia

Species	Percentage
Deer spp. (e.g. *Muntiacus muntjak & Rusa unicolor*)	45.3%
Sunda Bearded Pig (*Sus barbatus*)	42.0%
Eurasian Wild Pig (*Sus scrofa*)	39.1%
Squirrel spp. (not specified)	9.4%
Civet spp. (e.g. *Paradoxurus hermaphroditus & Viverra tangalunga*)	8.8%
Softshell Turtle (e.g. *Amyda cartilaginea & Dogania subplana*)	6.5%
Sumatran Serow (*Capricornis sumatraensis*)	6.2%
Flying Fox spp. (e.g. *Pteropus vampyrus & P. hypomelanus*)	5.5%
Porcupine spp. (e.g. *Hystrix brachyura*)	4.6%
Reticulated Python (*Python reticulatus*)	4.2%
Water Monitor Lizard (*Varanus salvator*)	3.3%
Estuarine Crocodile (*Crocodylus porosus*)	2.0%
Sun Bear (*Helarctos malayanus*)	2.0%
Long-tailed Macaque (*Macaca fascicularis*)	1.6%
Sunda Pangolin (*Manis javanica*)	1.6%
Tiger (*Panthera tigris jacksoni*)	1.0%
Red Junglefowl (*Gallus gallus*)	0.7%
Leopard (*Panthera pardus*)	0.7%
Asian Elephant (*Elephas maximus*)	0.3%
Monocled Cobra (*Naja kaouthia*)	0.3%
Tortoise spp. (not specified)	0.3%

The traded wildlife from Table 1 is further aggregated into taxonomic groups for *Felidae*, *Squamata*, *Testudines* and *Crocodylia* in order to better illustrate the differing percentage availabilities of wild meat as shown in Figure 1.

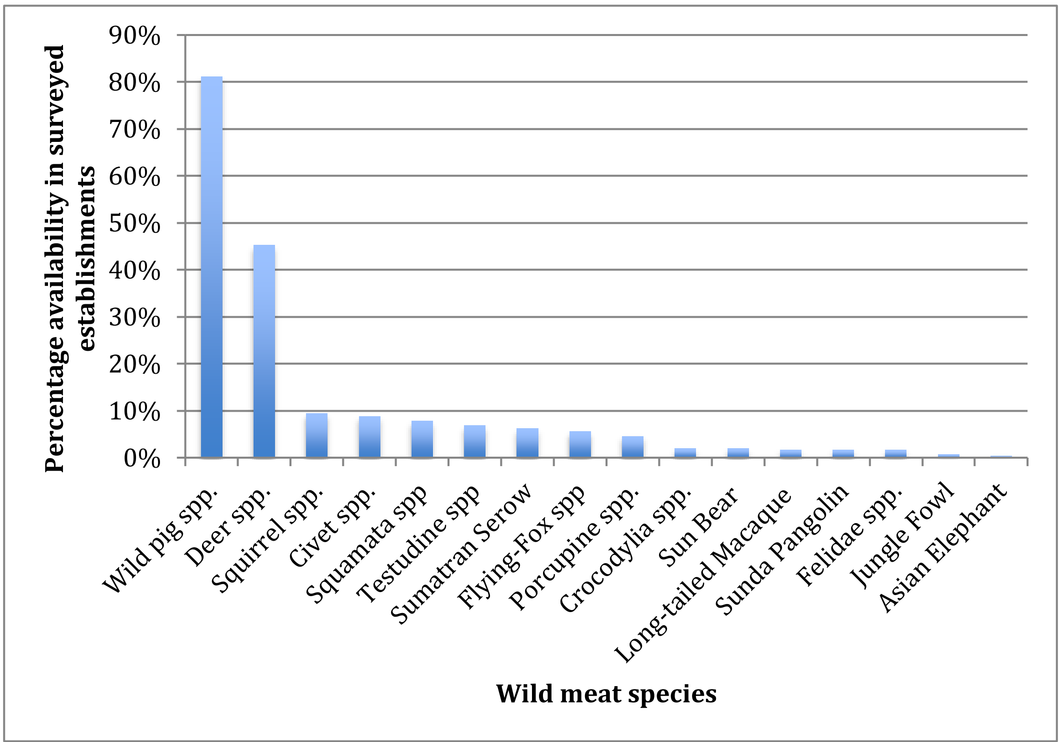

Figure 1: Wild meat availability in surveyed establishments across Malaysia shown in species groupings

Table 2 lists the specific species identified in the survey and when taxonomic classification was not possible to species level, the most likely species for consumption is given. This table also shows the IUCN Red List of Threatened Species category for each assessed species (obtained from the IUCN website database) to indicate their risk of extinction, which should be considered in relation to the wild meat trade. The IUCN database provides information on the major threats to the listed species and Table 2 indicates when hunting animals for meat has been listed as a specific threat. Within the table the answers are categorised as follows:

- "Yes" for evidence that hunting is a major threat to the species in Malaysia;
- "No" when there is no evidence that hunting is a major threat or if hunting levels are insufficiently high to threaten the species in Malaysia;
- A question mark for any uncertainty about the effect that hunting pressure has on populations in Malaysia or if data is minimal.

Table 2 shows that hunting for meat is identified as a significant conservation threat for 11 out of 23 species and a possible threat for 8 other species, which will be discussed in Section 2.3. This section will also examine the drivers and impacts of this trade on species sold in Malaysia in relation to:

- Wild meat availability survey results;
- Referenced literature on hunting wildlife for food;
- Species population data from Malaysia.

Table 2 also presents the geographical range within Malaysia of the species sold for wild meat (obtained from the IUCN Red List) because it may affect their availability in establishments across the three regions. Some qualitative data from the survey indicated that whilst the majority of wild meat sold was sourced in Malaysia, a proportion came from Thailand or Indonesia, which reflects the broad geographic ranges of several species. It should be considered whether populations of wildlife species with restricted ranges (e.g. *Pteropus hypomelanus* & *Capricornis sumatraensis*) could be particularly vulnerable to hunting pressures.

Table 2: IUCN Red List information about the status, geographic range and hunting threat of species identified as wild meat

Species	IUCN Red List status	Range (PM = Peninsular Malaysia, Sab = Sabah, Sar = Sarawak)	IUCN Listed hunting threat
Muntiacus muntjak	LC	PM, Sab & Sar	Yes
Rusa unicolor	VU	PM, Sab & Sar	Yes
Sus barbatus	VU	Southern PM, Sab & Sar	Yes
Sus scrofa	LC	PM	?
Paradoxurus hermaphroditus	LC	PM, Sab & Sar	No
Viverra tangalunga	LC	PM, Sab & Sar	No
Amyda cartilaginea	VU	PM, Sab & Sar	?
Dogania subplana	LC	PM, Sab & Sar	?
Capricornis sumatraensis	VU	PM	Yes
Pteropus vampyrus	NT	PM, Sab & Sar	?
Pteropus hypomelanus	LC	PM eastern & western coast islands	?
Hystrix brachyura	LC	PM, Sab & Sar	?
Python reticulatus	NA	PM, Sab & Sar	?
Varanus salvator subspecies	LC	PM, Sab & Sar	Yes
Crocodylus porosus	LC	PM, Sab & Sar	No
Helarctos malayanus	VU	PM, Sab & Sar	Yes
Macaca fascicularis	LC	PM, Sab & Sar	Yes
Manis javanica	CR	PM, Sab & Sar	Yes
Panthera tigris jacksoni	EN	PM	Yes
Gallus gallus	LC	PM, Sab & Sar	No
Panthera pardus	NT	PM	Yes
Elephas maximus	EN	PM & Sab	Yes
Naja kaouthia	LC	PM	?

Key: NA= Not Assessed, LC= Least Concern, VU= Vulnerable NT= Near Threatened, EN= Endangered, CR= Critically Endangered.

Finally, it should be recognised that the hunting of some wildlife species is illegal under Malaysian legislation and this poses challenges to conservation in relation to law enforcement. The unpublished report (Caillabet et al., Unpublished) has already described the three, different wildlife conservation legislative acts in Malaysia that have led to variations in the protection afforded to some species between regions, which include:

- The Wildlife Conservation Act 2010 in Peninsular Malaysia;
- The Sabah Wildlife Conservation Enactment 1997 in Sabah;
- The Wildlife Protection Ordinance 1998 in Sarawak.

Further evaluation of the legislation is beyond the scope of the dissertation.

2.3 Discussion

2.3.1 Wild pigs and deer

Figure 2: *Sus barbatus*[2]

Table 1 shows that wild pigs, *Sus barbatus* (42%) and *Sus scrofa* (39%), are the most commonly traded wild animals in Malaysia overall (total 81%) and deer (including *Muntiacus muntjak* and *Rusa unicolor*) are ranked second (45%). These results are similar to previously published data from Sarawak in 1996 as

[2] http://commons.wikimedia.org/wiki/File:Bearded-Pig.jpg

discussed in a review paper (Bennett and Rao, 2002), which highlighted the majority of wild meat traded here was from *S. barbatus*, *M. muntjak* and *R. unicolor*. More recent studies in Southeast Asia (Luskin et al., 2014; Pangau-Adam et al., 2012) have also indicated the increased commercial trade of wild pig and deer species for meat. In Malaysia, although religious prohibitions prevent the consumption of pigs by Muslims, other non-Muslim ethnicities (e.g. Chinese and aborigines) will eat pork supporting the high level of trade in wild pig meat. Some Malaysians favour wild venison as a prized delicacy so it is often served during religious festivals (Kasah, 2013) and in Sarawak this meat is often sold to logging crews (Bennett and Gumal, 2001), which all drives the commercial trade of venison to supply rural and urban consumers

The indigenous people of Peninsular Malaysia (known as Orang Asli) still continue their tradition of hunting of wildlife for personal consumption. A recent survey (Or and Leong, 2011) of Orang Asli inhabiting the Belum-Temengor Forest Complex indicated that *M. muntjak*, *R. unicolor* and *S. scrofa* were mainly killed to provide food for local hunting communities, but it also provided evidence for indigenous hunters being involved in the commercial wild meat trade. Other research has identified their involvement in illegal hunting at this location to supply middlemen with wild meat (Azrina et al., 2011).

The sustainability of the Malaysian trade in wild ungulate meat will vary between species within different regions depending upon a variety of factors including: their populations numbers, harvesting rates, commercial availability of meat, exposure to other anthropogenic threats and the effectiveness of law enforcement. The information from Tables 1 and 2 may assist in the sustainability assessment, but some deficiencies in knowledge about the listed factors will inhibit the overall analysis. The high availability of *S. barbatus* and *R. unicolor* meat, combined with their IUCN Red List categorisation as Vulnerable and the major threat from hunting could indicate that their trade may be unsustainable. Recent research has also provided evidence for population declines of some wild ungulate species in Malaysia related to hunting, which include:

- An analysis of 23 camera-trap studies throughout Peninsular Malaysia indicated *R. unicolor* population declines, with it rarely being seen outside of protected areas (Kawanishi et al., 2013).

- An interview-based survey of hunters and dealers assessed their perceptions of changes in ungulate species abundance in Peninsular Malaysia and highlighted depleted numbers of deer at three out of five sites studied (Goldthorpe and Neo, 2011).
- Camera-trap studies in Peninsular Malaysia indicated that *S. barbatus* was one of the least observed ungulate species and its distribution has been reduced to the Southern half of this region (Kawanishi et al., 2006).

By contrast, *S. scrofa* is IUCN listed as Least Concern since it is relatively abundant in Malaysia with a questionable threat from hunting (see Table 2) and it is often regarded as a pest species.

Overall, the TRAFFIC data and published literature support concerns about the over-harvesting of some wild pig and deer species in Malaysia for meat. Further surveys could compare population abundance and density of these species between areas of different hunting intensity in order to assess the effects of this harvesting and determine conservation measures to reduce their trade.

2.3.2 Sumatran serow

Figure 3: *Capricornis sumatraensis*[3]

Capricornis sumatraensis is another large ungulate sold for wild meat (representing around 6% of the trade) that may now be in decline within Malaysia due to illegal hunting as indicated by 10-year seizure records (Shepherd and Krishnasamy, 2014a), but the lack of reliable population estimates prevents full analysis of this threat. Despite *C. sumatraensis* being listed as Totally Protected under the Wildlife Conservation Act 2010, it was the most frequently encountered Totally Protected species sold in restaurants of Peninsular Malaysia, which may be related to its meat being highly prized (Shepherd and Krishnasamy, 2014a). Additional research is required to assess whether the major threat of poaching may further endanger this serow in Malaysia.

[3] http://commons.wikimedia.org/wiki/File:Serow_Capricornis_sumatraensis.JPG

2.3.3 Squirrels and Civets

Figure 4: ***Paradoxurus hermaphroditus***[4]

Squirrel (e.g. *Callosciurus spp*.) and civet species (e.g. *Paradoxurus hermaphroditus* shown in Figure 4) combined represent almost 20% of the wild meat trade in Malaysia. These small mammals have been a common food for hunting communities in tropical Asia (Corlett, 2007) because they can easily be captured using snares, blowpipes or darts in comparison to the challenges of hunting larger, more aggressive mammals and they remain a popular food for some rural inhabitants of Southeast Asia, e.g. in the Philippines (Scheffers et al., 2012). Civet meat is also a favoured food for the ethnic Chinese (Corlett, 2007). A recent report based upon six-year seizure records for viverrids (Shepherd and Shepherd, 2010) has suggested that the illegal hunting and trade of civet species for meat is widespread throughout Peninsular Malaysia to supply local and international markets, despite protection afforded by conservation legislation. The absence of civet population data from Malaysia makes it difficult to assess the consequences of this trade on wild populations and further research is required to understand if hunting should be considered a major threat to civet species here, which could alter their IUCN listing.

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[4] http://commons.wikimedia.org/wiki/File:Marapatti.jpg

2.3.4 Reptiles

Figure 5: *Python reticulatus*[5]

Table 1 shows that reptile species from *Squamata*, *Testudines* and *Crocodylia* orders comprise over 16% of the wild meat trade. Whilst the domestic market for reptile meat is important, the significant involvement of Malaysia in the global reptile trade should be recognised and recent seizure data (Nijman, 2010) has provided evidence for the massive illegal exportation of turtles, monitor lizards and snakes from this country. Therefore, the domestic trade may only contribute a small percentage to the overall trade of Malaysian reptiles for food in this region.

The traditional consumption of reptiles by some indigenous tribes has been studied in Malaysia. For example, the diet of Senoi, Negrito and Temuan aborigines in Peninsular Malaysia often includes snake meat, with python being particularly favoured (Prathap et al., 1969) and the indigenous people of Malaysian Borneo (Latif et al., 2011) also commonly eat it. The popularity of snake meat has now extended from rural to urban areas where customers are supplied with this delicacy in specialty restaurants. The increased demand for snake meat in combination with the international trade of reptiles from Southeast Asia for their skins or the pet industry (Nijman, 2010) could be highly detrimental for wild snake populations in Malaysia. However, the lack of population data on *Python reticulatus* (Figure 5) and *Naja kaouthia* and the unknown level of threat

[5] http://commons.wikimedia.org/wiki/File:Retic1.jpg

posed by the wild meat trade (see Table 2) limits an assessment of hunting sustainability. In contrast to snakes, the IUCN Red List recognises the major threat from the hunting of *Varanus salvator* lizards for consumption in Malaysia.

Figure 6: Juvenile *Amyda cartilaginea*[6]

Softshell turtle and tortoise species represent only 6.5% and 0.3% respectively of the wild meat traded in Malaysia (see Table 1). These figures are relatively low considering that published literature (Sharma and Tisen, 1999) has explained their significant utilisation as food sources in Malaysia. This may be related to the exclusion of softshell turtles sold in Peninsular Malaysia from the survey dataset due to their commercial farming here, which could have led to the under-reporting of wild-caught individuals. The survey methodology may also have contributed to the under-reporting of some turtle and tortoise species, as will be discussed in Section 2.4.

Freshwater turtles (particularly *Amyda cartilaginea* and *Dogania subplana*) are an important traditional food for many aboriginal Malaysians (Sharma, 1999) and their meat provides a valuable protein source for rural communities (Jensen and Das, 2008). In addition, *A. cartilaginea* is regarded as a delicacy by Chinese Malaysians who eat turtle soup (using the meat and cartilaginous portions of the shell) for its medicinal value (Sharma, 1999) and it is the most commonly sold

[6] http://commons.wikimedia.org/wiki/File:Amyd_cartil_090818-11809_tsa.jpg?fastcci_from=8684160

softshell turtle species in Chinese restaurants and wet markets (Sharma and Tisen, 1999). In Sarawak, those indigenous people who have relocated to urban areas still retain cultural food preferences for turtle meat thus sustaining the demand (Jensen and Das, 2008). By contrast, the Muslim community is forbidden from eating turtle meat due to Islamic dietary rules (Sharma, 1999), but Muslim communities living by rivers will harvest both listed species as a useful cash crop to supply commercial markets (Sharma and Tisen, 1999). Although the harvesting and consumption of softshell turtle eggs commonly occurs in Malaysia (Sharma and Tisen, 1999), the TRAFFIC survey did not include data on egg sales and the detrimental effects of this exploitation on their populations could not be examined. The high demand for turtles in Malaysia to satisfy cultural and medicinal purposes is a serious concern for the sustainability of this trade, especially when considering the life history traits of these long-lived reptiles.

Table 2 shows that *A. cartilaginea* is listed as Vulnerable and population declines have been recognised in Malaysia, where market numbers for this formerly abundant species have decreased since the 1970's (Altherr and Freyer, 2000). Similarly, the intensive trapping of *D. subplana* from accessible riverine habitats fragmented by logging have also reduced local populations in some areas (Sharma and Tisen, 1999). There have been recommendations for further field studies on softshell turtle species across Malaysia in order to provide population estimates (Jensen and Das, 2008) that could be utilised in combination with harvesting data to enable a more accurate assessment of their trade for food. The variation in legal protection for *A. cartilaginea* and *D. subplana* between Peninsular Malaysia, Sabah and Sarawak also complicates conservation strategies aiming to reduce their exploitation.

2.3.5 Flying-Foxes

Figure 7: *Pteropus vampyrus*[7]

The flying-fox species, *Pteropus vampyrus* (Figure 7) and *P. hypomelanus* are relatively popular as wild meat, with trade availability at 5.5% from Table 1. Their behaviour of tree roosting in large colonies enables hunters to easily capture them for food, but the low reproductive rate of these species increases their vulnerability to over-harvesting (Mickleburgh et al., 2009).

One review (Mickleburgh et al., 2009) has identified extensive, commercial harvesting of flying-foxes to supply both rural and urban markets that now threaten some populations, especially in Southeast Asia (e.g. the Philippines, Indonesia and Malaysia). Specific studies of *P. vampyrus* colonies in Peninsular Malaysia (Epstein et al., 2009; Mohd-Azlan et al., 2001) and Sarawak (Gumal et al., 1997) have shown significant declines in abundance and distribution likely related to the combined effects of over-hunting and habitat loss. Consequently, *P. vampyrus* is now categorised as Near Threatened (see Table 2). Whilst the meat from this species often supports subsistence livelihoods in Sarawak, it may also be

[7] http://upload.wikimedia.org/wikipedia/commons/0/0c/Pteropus_vampyrus_headshot.jpeg

sold as luxury food (Gumal et al., 1997) and is often consumed by ethnic Chinese Malaysians on special occasions (Mickleburgh et al., 2009). One study used *P. vampyrus* population models to indicate that an unsustainable level of hunting was occurring in Malaysia of potential threat to the regional population (Epstein et al., 2009). The combination of published literature and data from this report should encourage further examination of the effects that this trade has on flying fox populations in order to facilitate improvements in legal protection for these species within Malaysia.

2.3.6 Pangolins

Figure 8: *Manis javanica*[8]

The commercial hunting of pangolin species in Asia threatens many of their populations (Corlett, 2007) and *Manis javanica* (Figure 8) is now Critically Endangered. It is therefore surprising that sales of *M. javanica* only represent 1.6% of the wild meat trade, shown in Table 1. The deficiency of population data for this secretive and nocturnal species in Malaysia has prevented an accurate assessment of hunting pressure on its survival, but the IUCN Red List has

[8] http://commons.wikimedia.org/wiki/File:Pangolin_borneo.jpg

recognised its trade as a major threat to populations here (see Table 2) despite its legal protection. A recent report interviewed pangolin hunters in Sabah (Pantel and Awang Anak, 2010) and discovered that criminal syndicates were involved in the illegal, international *M. javanica* trade. This research suggested that Malaysia supplies large numbers of them to China and Vietnam (where pangolin meat and scales are highly prized) and so this species was rarely consumed in Sabah because of its high export value. The low percentage availability of *M. javanica* identified in this dissertation certainly reflects the report's findings. However, another interview-based survey conducted in Peninsular Malaysia (Chin and Pantel, 2009) examined *M. javanica* trade dynamics and found that 31% of pangolins hunted were for local consumption. Consequently, conservation initiatives for *M. javanica* in different regions of Malaysia may need to focus on reducing pangolin supply to both international and domestic markets.

2.3.7 Sun bears, Tigers and Asian Elephants

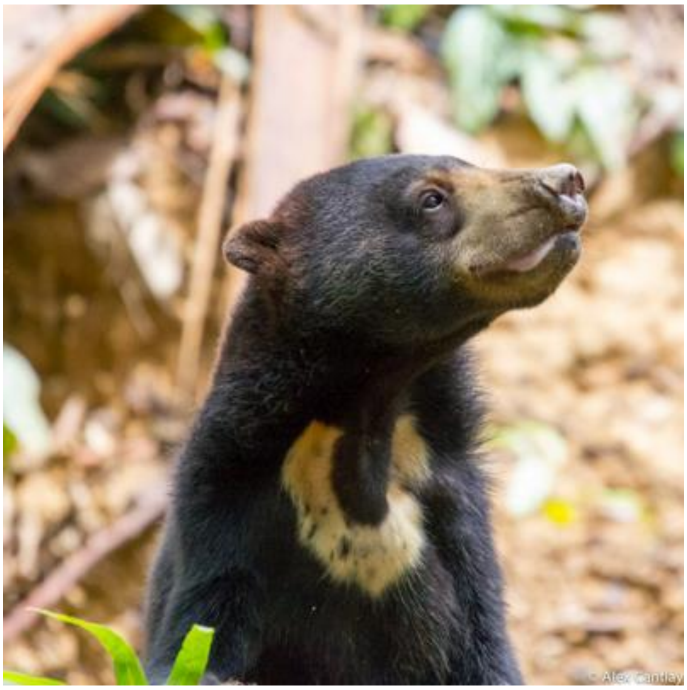


Figure 9: *Helarctos malayanus*[9]

[9] http://wombat.smugmug.com/Travel/Borneo/i-qdmNX2H/A

Although Table 1 indicates that the availability of wild meat from *Helarctos malayanus* (Figure 9), *Panthera tigris jacksoni* and *Elephas maximus* is low (between 0.3 and 2.0%), their IUCN Red List status as Vulnerable or Endangered raises concerns as to whether their utilisation for food could endanger populations in Malaysia. Table 2 indicates that hunting of these species for wild meat is considered a major threat to populations here.

The risk of extinction is a distinct possibility for *P. t. jacksoni* where the national population estimate has declined over the last decade, from between 493 to 1480 adult tigers (Kawanishi et al., 2003) to the significantly lower estimate of around 300 individuals (MYCAT, 2014). The wild meat trade in combination with other anthropogenic threats e.g. habitat loss, traditional Chinese medicines use of tiger parts, prey depletion and human-wildlife conflict (Kawanishi, 2012) all contribute to increase tiger extinction risk. The increased wealth within Asian society has enabled more consumers to purchase highly desirable tiger parts and products (Dinerstein et al., 2007) and so the commercial poaching of tigers for meat consumption is only one small part of their overall trade.

The wild meat trade may also threaten the relatively small *E. maximus* populations estimated at between 1223 and 1677 individuals in Peninsular Malaysia (Saaban et al., 2011) and around 2040 in Sabah (Alfred and Ahmad, 2010).

Despite minimal quantitative data on *H. malayanus* population sizes, local declines have occurred in Sabah (Te Wong et al., 2005) due to the combined effects of climatic variation (prolonged droughts disrupting fruiting patterns) and human activities (habitat loss and hunting). A recent report (Shepherd and Krishnasamy, 2014b) also highlighted the importance of the commercial *H. malayanus* trade in Sarawak for their meat, paws and gall bladders that is exerting pressure on wild populations. Therefore, the impacts of the wild meat trade on Malaysian wildlife should be examined in combination with other anthropogenic threats and natural events to determine effective conservation strategies.

2.3.8 Red Junglefowl

Figure 10: *Gallus gallus*[10]

The only bird species identified in the survey is the IUCN-listed Least Concern *Gallus gallus* (Figure 10), which is found in 0.7% of wild meat establishments (Table 1). These results are unexpected considering the high level of trade in *Galliformes* occurring within Southeast Asia (Shepherd and Nijman, 2009) and limitations in the survey methodology could have led to *Galliformes* being under-represented, thus further investigations on their trade in Malaysia would be advisable. Whilst this dissertation indicates the apparently low availability of wild bird meat within Malaysia, seizure data has suggested that this country is an important exporter of bird meat (e.g. owls) to China (Shepherd and Shepherd, 2009) that could have significant impacts upon wild bird populations.

[10] http://commons.wikimedia.org/wiki/File:Red_Junglefowl.jpg

2.4 Concluding Remarks

The limitations of the market-based survey were already discussed in the TRAFFIC report (Caillabet et al., Unpublished), which included the inability to survey all establishments, the difficulty of identifying wild meat to a species level and the variation in quality of information provided by restaurant staff. Therefore, it should be recognised that the methods used may have under-estimated the scale of the wild meat trade in Malaysia. It should be noted that this preliminary survey was conducted over a relatively short period of time that may have limited the potential number of species identified for trade. Ideally this type of market-based survey should be performed over a longer period of time to enable an increased frequency of visits to wild meat establishments in order to provide a larger dataset and possibly a more accurate representation of the variety of species traded.

The survey has provided useful initial data for the assessment of the availability of wild meat in Malaysian establishments that will assist in raising the profile of this wildlife exploitation issue. Further studies in Malaysia involving field-based observations to determine population estimates of the traded wildlife species and examine hunting patterns would be advisable. In addition, interview-based surveys to investigate household consumption patterns and consumer behaviour would be beneficial in understanding the different cultural, religious, economic and nutritional drivers of this trade at local and regional levels.

3. Zoonotic Diseases Literature Review

This section aims to present epidemiological evidence for the identification of zoonotic viral, bacterial and parasitic pathogens in the species commonly traded for wild meat in Malaysia (discussed in Section 2) in order to evaluate transmission risks to humans.

3.1 Identification of zoonotic pathogens

3.1.1 Methodology

Surveys of wild animal populations (involving serological, post mortem and faecal sampling) for infectious agents and disease outbreak investigations have provided valuable data on the potential zoonotic pathogens circulating in wildlife hosts. The risk of cross-species pathogen transmission to humans has been identified using disease case reports, particularly in reference to wildlife hunters and consumers. Serological surveys of some human populations (e.g. indigenous tribes with hunting traditions or animal workers) have also illustrated the increased risk for zoonotic infections due to certain behaviours. The scientific literature has been sourced from online journal resources (e.g. The University of Edinburgh library, Research Gate and Google Scholar) and disease reporting databases (e.g. Pro Med).

In some cases, insufficient published literature about a wildlife species has required the use of information from another species within the same taxonomic family or order, making the assumption that they would be infected by similar pathogens. This assumption may be reasonable for those species with similar ecology, but significant variations could affect their prevalences of infection. For example, the lack of pathogen research concerning omnivorous *H. melayanus* has led to the usage of published literature on other bear species, including carnivorous *Ursus maritimus*. However, the high prevalence of *Trichinella* infections reported in adult *U. maritimus* associated with their scavenging and cannibalism (Born and Henriksen, 1990) may not occur in *H. melayanus* because this species does not exhibit such feeding behaviour. Therefore, the scientific data from other species (not listed in Table 1) can only offer reasonable suggestions for possible pathogen infections.

Sometimes the lack of pathogen data from wildlife in Southeast Asia has led to an examination of the global literature. The geographic distribution of infectious agents has been considered and excludes those located in non-Asian regions. Additionally, it was preferable to examine data collected from free-ranging rather than captive populations of wildlife since in Malaysia animals are mainly hunted from the wild to supply the meat trade. References in Tables A1 to A3 have noted when research has been used from captive populations because the environmental conditions related to captivity could have influenced pathogen diversity and frequency.

3.2 Overview of results

The full details of the potential zoonotic viral, bacterial and parasitic pathogens from wildlife taxa involved in the Malaysian wild meat trade are presented in Tables A1, A2 and A3 of the appendix. The information is summarised in Tables 3, 4 and 5 of this section in order to highlight which pathogens commonly infect a wide variety of wildlife hosts.

Table 3 indicates that *Pteropodidae* and *Cercopithecidae* species harbour the greatest number of viral pathogens. The gregarious nature and longevity of *Pteropodidae* bats living within large roosting colonies at high population densities increases the likelihood of virus transmission between individuals to maintain infection (Calisher et al., 2006). Similarly, the complex social behaviour of *Cercopithecidae* groups and aggressive interactions may also facilitate viral spread (Wolfe et al., 1998). The relative popularity of *Pteropus* wild meat and the genetic similarities between *Cercopithecidae* primates and humans are of significance for viral cross-species transmission to people involved in this trade.

The greatest range of bacterial pathogens is found in the most commonly traded wild animals, *Suidae* and *Cervidae*, shown in Table 4. These taxa usually live in family groups and frequent social contact between individuals may promote bacterial transmission between them, via infected body fluids or faeces. The most significant bacteria from both taxa will be discussed later in this section.

Table 5 suggests that parasites of *Sarcocystis, Toxoplasma* and *Trichinella* species are most frequently identified in the listed taxa. Their lifecycles involve multiple wildlife hosts and hunting could potentially increase the risk of parasite transmission to humans who may become intermediate or abnormal hosts. The greatest number of zoonotic parasites are found in *Cercopithecidae*, of concern for human health given the increased contact between primates and humans at fragmented forest environments, which was highlighted by the gastrointestinal parasite study of a *Macaca silenus* population in India (Hussain et al., 2013). This research may be applicable to Malaysia where high rates of deforestation and hunting could influence the parasite burden of *Macaca* species found here.

The deficiency of published research on *Hystricidae* and *Manidae* families significantly limits the presentation of information about their potential zoonotic risks to humans. This lack of data could be related to the difficulty of observing these animals in their natural habitats due to their small size and secretive behaviour. Future surveys of infectious agents in *Hystricidae* and *Manidae* populations would be required to advance scientific knowledge.

Table 3: Potential zoonotic viral pathogens from wildlife involved in the wild meat trade

	Wildlife host (taxonomic order or family)															
Virus	**Suidae**	**Cervidae**	**Sciuridae**	**Viverridae**	**Caprinae**	**Pteropodidae**	**Hystricidae**	**Ursidae**	**Cercopithecidae**	**Felidae**	**Manidae**	**Elephantidae**	**Squamata**	**Testudines**	**Crocodylia**	**Galliformes**
Avian paramyxovirus-1																**X**
Cercopithecine herpesvirus-1									**X**							
Cowpox virus (Orthopoxvirus)												**X**				
Ebola virus subtype Reston						**X**			**X**							
Hepatitis E virus	**X**	**X**														
Highly pathogenic avian influenza virus				**X**						**X**						**X**
Lymphocytic choriomeningitis virus			**X**													
Nipah virus						**X**										
Orf virus (Parapoxvirus)		**X**			**X**											
Rabies virus and related *Lyssaviruses*			**X**	**X**		**X**		**X**	**X**	**X**						
Reoviruses (e.g. *Melaka virus*)						**X**										
SARS Coronavirus*				**X**		**X**										
Simian foamy virus									**X**							
Simian type D retrovirus									**X**							
Simian virus 40									**X**							
Swine influenza virus	**X**															

*SARS= Severe Acute Respiratory Syndrome

Table 4: Potential zoonotic bacterial pathogens from wildlife involved in the wild meat

	Wildlife host (taxonomic order or family)															
Bacteria	**Suidae**	**Cervidae**	**Sciuridae**	**Viverridae**	**Caprinae**	**Pteropodidae**	**Hystricidae**	**Ursidae**	**Cercopithecidae**	**Felidae**	**Manidae**	**Elephantidae**	**Squamata**	**Testudines**	**Crocodylia**	**Galliformes**
Bacillus anthracis	**X**	**X**										**X**				
Bartonella henselae				**X**						**X**						
Brucella spp	**X**	**X**			**X**			**X**								
Campylobacter spp	**X**	**X**		**X**	**X**				**X**				**X**	**X**		**X**
Chlamydophila spp	**X**	**X**			**X**											**X**
Dermatophilus congolensis													**X**	**X**	**X**	
Edwardsiella tarda													**X**	**X**	**X**	
Erysipelothrix rhusiopathiae	**X**	**X**														**X**
Escherichia coli (shiga-toxin producing)	**X**	**X**			**X**											
Francisella tularensis	**X**		**X**					**X**								
Leptospira spp	**X**	**X**	**X**		**X**	**X**	**X**	**X**	**X**	**X**						
Mycobacterium tuberculosis complex	**X**	**X**			**X**				**X**			**X**				
Other *Mycobacterium* spp									**X**							**X**
Pasteurella spp										**X**						
Salmonella spp	**X**	**X**		**X**	**X**	**X**			**X**				**X**	**X**	**X**	**X**
Shigella spp									**X**							
Streptococcus spp	**X**			**X**												
Yersinia pestis		**X**	**X**					**X**		**X**						
Other *Yersinia* spp	**X**	**X**		**X**		**X**										**X**

Table 5: Potential parasitic pathogens from wildlife involved in the wild meat

Parasite	Wildlife host (taxonomic order or family)															
	Suidae	**Cervidae**	**Sciuridae**	**Viverridae**	**Caprinae**	**Pteropodidae**	**Hystricidae**	**Ursidae**	**Cercopithecidae**	**Felidae**	**Manidae**	**Elephantidae**	**Squamata**	**Testudines**	**Crocodylia**	**Galliformes**
Ancyclostoma spp									X							
Anisakidae spp															X	
Balantidium coli	X								X							
Cryptosporidium spp	X	X							X	X		X				X
Enantomoeba histolytica									X							
Giardia spp	X	X							X							
Gnathostoma spp				X									X			
Oesophagostomum spp									X							
Pentastomidia spp													X	X	X	
Sarcocystis spp		X	X	X				X	X				X			X
Spirometra spp	X												X			
Strongyloides spp									X							
Taenia spp	X															
Toxoplasma gondii	X	X	X	X	X			X	X	X						
Trichinella spp	X	X						X		X			X		X	
Trichuris spp	X								X							

3.3 Disease Transmission Risks

The literature review has examined the potential transmission risks from zoonotic pathogens associated with the hunting (capture and handling of animals), meat processing (evisceration, skinning and cutting of carcasses for food preparation) and consumption of wild meat, for the taxa identified in Section 2.2 and the overall results are shown in Tables A1, A2 and A3. Vector-borne pathogens have been excluded from this review because their indirect transmission route is of less concern for the wild meat trade.

3.3.1 Hunting

The capture of live animals can cause bites and scratches to humans leading to the transcutaneous route of infection. Direct pathogen transmission from animal blood into the human bloodstream can occur when the hunter handling the animal already has open wounds on his hands, forearms or torso (LeBreton et al., 2006).

3.3.2 Meat Processing

The people who process carcasses risk infection from direct contact with animal blood, excretions or secretions, especially if they have skin abrasions or wounds (LeBreton et al., 2006). Field-dressing is often performed by hunters without protective equipment that can lead to self-inflicted knife injuries (Eales et al., 2010), which facilitates blood-borne pathogen transmission. Butchering may enable zoonotic infection through a variety of other transmission routes, including transcutaneous, mucosal, inhalation or faeco-oral.

3.3.3 Consumption

Field-dressing carcasses in the outdoor environment may often lead to microbiological contamination of wild meat that has been related to the killing method (Paulsen, 2011), unhygienic practices and time delays to refrigeration (Gill, 2007). This increases the risk for human ingestion of zoonotic pathogens from eating wild meat or inadvertent infection during food preparation, which may cause disease. The cultural food preferences for eating raw or undercooked wild meat by some aboriginal tribes in Malaysia (Latif et al., 2011) also increases the foodborne transmission risk for particular pathogens, normally killed by cooking.

3.3.4 Presentation of information

Tables A1 to A3 present the potential zoonotic risks from wildlife hunting, butchering and consumption and describe the most likely routes of infection to humans for each pathogen, whilst highlighting any uncertainties in the literature. Tables A1 to A3 provide a comprehensive summary of possible zoonotic infections from traded wildlife based upon referenced evidence from different countries. Human case reports from Southeast Asia have been utilised whenever possible, but the under-reporting of diseases in this region (Coker et al., 2011) may have underestimated the impact of wildlife-associated zoonotic disease that is presented in this review.

The transmission routes and risks for each pathogen are also presented in Table 6 that summarises information in an easily readable format. This table illustrates that viral transmission to humans often depends upon direct contact with animal body fluids, whereas parasites commonly rely upon foodborne and faeco-oral routes and bacteria use many transmission routes.

Table 6: Transmission risks from the potential zoonotic pathogens

Type of pathogen	Pathogen species	Human disease description	Potential transmission route from wildlife to human	Potential zoonotic risk from hunting, butchering or consumption
Virus	*Avian paramyxovirus-1* (Newcastle disease)	Conjunctivitis or influenza-like disease	Contact with large amounts of virus from infected birds or their carcasses e.g. inhalation.	Hunting Butchering
	Cercopithecine herpesvirus-1	Herpes B virus disease	Transcutaneous: via animal bites or scratches. Non-bite exposure: via mucous membranes or damaged skin.	Hunting Butchering
	Cowpox virus (Orthopoxvirus)	Cowpox	Transcutaneous: via animal bites, scratches or damaged skin.	Hunting Butchering
	Ebola virus (subtype Reston)	Ebola haemorrhagic fever	Contact with infected animals, body fluids & tissues.	Hunting Butchering
	Hepatitis E virus	Hepatitis E	Foodborne. Faeco-oral ? Direct contact with infected animal blood?	Consumption Hunting? Butchering?
	Highly pathogenic avian influenza virus	Avian influenza	Contact with infected respiratory secretions. Ingestion of blood or undercooked meat? Faeco-oral ?	Hunting Butchering Consumption?
	Lymphocytic choriomeningitis virus	Lymphocytic choriomeningitis	Transcutaneous: via animal bites. Contact with infected animal excretions & secretions.	Hunting Butchering

Type of pathogen	Pathogen species	Human disease description	Potential transmission route from wildlife to human	Potential zoonotic risk from hunting, butchering or consumption
	Nipah virus	Nipah virus infection	Ingestion of virus-contaminated food products Contact with infected urine or saliva or tissues.	Consumption Hunting Butchering
	Orf virus (Parapoxvirus)	Contagious ecthyma	Transcutaneous: via damaged skin or wounds.	Hunting Butchering
	Rabies virus and related *Lyssaviruses*	Rabies and rabies-related disease	Transcutaneous: via animal bites and scratches. Non-bite exposure: via mucous membranes or damaged skin.	Hunting Butchering
	Reoviruses (e.g. *Melaka virus, Pulau virus)*	Acute respiratory disease	Direct transmission from bat to human occurs via close contact?	Hunting? Butchering?
	SARS Coronavirus*	SARS	Mucosal transmission: contact with virus-infected respiratory droplets. Indirect transmission via virus-contaminated fomites.	Hunting Butchering
	Simian foamy virus	Simian foamy virus infection	Transcutaneous and mucosal: via animal bites, scratches and saliva splashes.	Hunting Butchering
	Simian type D retrovirus	Persistently seropositive humans without disease	Transcutaneous and mucosal: via animal bites, scratches and saliva splashes?	Hunting? Butchering?
	Simian virus 40	Role in human cancers?	Transcutaneous and mucosal: via animal bites, scratches and saliva splashes.	Hunting Butchering
	Swine influenza virus	Swine influenza	Contact with infected respiratory secretions.	Hunting Butchering

Type of pathogen	Pathogen species	Human disease description	Potential transmission route from wildlife to human	Potential zoonotic risk from hunting, butchering or consumption
Bacteria	*Bacillus anthracis*	Anthrax	Foodborne. Transcutaneous: contact with contaminated carcasses & animal products. Inhalation of spores (rare).	Consumption Butchering
	Bartonella henselae	Cat scratch disease	Transcutaneous via animal bites and scratches.	Hunting
	Brucella spp	Brucellosis	Foodborne. Transcutaneous and mucosal: contact with infected bodily fluids or tissues.	Consumption Hunting Butchering
	Campylobacter spp	Campylobacter enteritis	Foodborne. Faeco-oral.	Consumption Hunting Butchering
	Chlamydophilia spp	Chlamydiosis Psittacosis (from birds)	Transcutaneous & aerogenous: contact with infected secretions or excretions. Inhalation of infected respiratory secretions or dried faeces.	Hunting Butchering Hunting Butchering
	Dermatophilus congolensis	Dermatophilosis	Transcutaneous: direct contact with infected lesions.	Hunting Butchering
	Edwardsiella tarda	Edwardsiellosis	Foodborne. Faeco-oral. Transcutaneous: via a wound.	Consumption Hunting Butchering
	Erysipelothrix rhusiopathiae	Erysipeloid	Foodborne. Transcutaneous: direct contact with infected animal products via damaged skin/wounds.	Consumption Butchering

Type of pathogen	Pathogen species	Human disease description	Potential transmission route from wildlife to human	Potential zoonotic risk from hunting, butchering or consumption
	Escherichia coli (Shiga-toxin producing) spp	Enterohaemorrhagic E.coli infections	Foodborne. Faecal-oral.	Consumption Hunting Butchering
	Francisella tularensis	Tularemia	Foodborne. Transcutaneous or mucosal: direct contact with infected animals. Inhalation of aerosolised bacteria.	Consumption Hunting Butchering
	Leptospira spp	Leptospirosis	Foodborne: urine-contaminated meat. Transcutaneous or mucosal: contact with infected urine.	Consumption Hunting Butchering
	Mycobacterium tuberculosis complex (M. tuberculosis and M. bovis)	Tuberculosis	Foodborne. Transcutaneous: direct contact via damaged skin/wounds. Inhalation of aerosolised bacteria.	Consumption Hunting Butchering
	Other *Mycobacterium* spp	Mycobacteriosis	Inhalation or ingestion of aerosolised bacteria.	Butchering
	Pasteurella spp	Pasteurellosis	Transcutaneous: via animal bites.	Hunting
	Salmonella spp	Salmonellosis	Foodborne. Faecal-oral. Transcutaneous: via animal bites and scratches.	Consumption Hunting Butchering

Type of pathogen	Pathogen species	Human disease description	Potential transmission route from wildlife to human	Potential zoonotic risk from hunting, butchering or consumption
	Shigella spp	Shigellosis	Foodborne: faecal-contaminated meat. Faeco-oral.	Consumption Hunting Butchering
	Streptococcus spp	Streptococcosis	Transcutaneous: direct contact via damaged skin/wounds.	Hunting Butchering
	Yersinia pestis	Plague	Transcutaneous or mucosal: contact with infected animals or carcasses. Inhalation of aerosolised bacteria.	Hunting Butchering
	Other *Yersinia* spp	Yersiniosis	Foodborne. Faeco-oral.	Consumption Hunting Butchering
Parasite	*Ancyclostoma* spp	Cutaneous larva migrans	Transcutaneous: infective larvae that penetrate skin.	Butchering
	Anisakidae spp	Anisakiasis	Foodborne: infective larvae in meat.	Consumption
	Balantidium coli	Balantidiasis	Foodborne: faecal-contaminated meat. Faeco-oral: ingestion of cysts.	Consumption Hunting Butchering
	Cryptosporidium spp	Cryptosporidiosis	Foodborne: faecal-contaminated meat. Faeco-oral: ingestion of oocysts.	Consumption Hunting Butchering
	Enantomoeba histolytica	Amoebiasis	Foodborne: faecal-contaminated meat. Faeco-oral: ingestion of cysts.	Consumption Hunting Butchering

Type of pathogen	Pathogen species	Human disease description	Potential transmission route from wildlife to human	Potential zoonotic risk from hunting, butchering or consumption
	Giardia spp	Giardiasis	Foodborne: faecal-contaminated meat. Faeco-oral: ingestion of cysts.	Consumption Hunting Butchering
	Gnathostoma spp	Gnathostomiasis	Foodborne: infective larvae in meat.	Consumption
	Oesophagostomum spp	Oesophagostomiasis	Foodborne: faecal-contaminated meat. Faeco-oral: ingestion of filariform larvae.	Consumption Hunting Butchering
	Pentastomidia spp	Pentastomiasis	Foodborne: infective larvae in meat. Faeco-oral: ingestion of eggs. Direct contact with infected animal tissues and respiratory secretions.	Consumption Hunting Butchering
	Sarcocystis spp	Sarcocystosis	Foodborne: infective sarcocysts in meat from intermediate host or faecal-contaminated meat from definitive host. Faeco-oral: ingestion of oocysts shed by definitive host.	Consumption Hunting Butchering
	Spirometra spp	Sparganosis	Foodborne: infective larvae in meat from the second intermediate host.	Consumption
	Strongyloides spp	Strongyloidiasis	Transcutaneous or mucosal: infective larvae from faeces that penetrate the skin or mucous membranes.	Hunting Butchering

Type of pathogen	Pathogen species	Human disease description	Potential transmission route from wildlife to human	Potential zoonotic risk from hunting, butchering or consumption
	Taenia spp	Taeniasis	Foodborne: infective larvae in meat /viscera from the intermediate host.	Consumption
	Toxoplasma gondii	Toxoplasmosis	Foodborne: infective cysts in meat from the intermediate host or faecal-contaminated meat from definitive host. Faeco-oral: ingestion of oocysts shed by definitive host.	Consumption Hunting Butchering
	Trichinella spp	Trichinellosis	Foodborne: infective cysts in meat.	Consumption
	Trichuris spp	Trichuriasis	Foodborne: faecal-contaminated meat. Faeco-oral: ingestion of embryonated eggs.	Consumption Hunting Butchering

* SARS= Severe Acute Respiratory Syndrome

3.4 Zoonotic Infection Risks From Selected Taxa

This section discusses the important zoonotic pathogens hosted by commonly traded wildlife taxa, utilising the information from Tables A1 to A3. Finally, it highlights some emerging zoonotic infections from flying-foxes of significance to the Malaysian wild meat trade.

3.4.1 Wild Pig Species

S. barbatus and *S. scrofa* are the most commonly available animals in the wild meat trade that also harbour a significant number of zoonotic pathogens, as indicated in Tables 3 to 5. The majority of information has been provided by the extensive global literature on *S. scrofa* rather than *S. barbatus* and it has been assumed that the latter could also host these pathogens, but future surveys of *S. barbatus* in Malaysia are required to substantiate this assumption.

Viruses

Hepatitis E Virus (HEV)

HEV genotypes 3 and 4 have led to sporadic cases of human disease in wild pig consumers (Meng et al., 2009), with the latter genotype mainly distributed in Asian countries (Okamoto, 2007). Case reports from Japan (referenced in Table A1) have provided evidence for HEV transmission to humans associated with the consumption of raw or undercooked wild pig meat or liver and HEV genetic sequence comparison between an infected patient and the meat consumed has confirmed foodborne transmission (Li et al., 2005b). Furthermore, a case-control study indicated that the ingestion of wild pig meat was independently associated with autochthonous HEV infection (Wichmann et al., 2008). Some serological surveys (examples in Table A1) have detected anti-HEV antibodies and HEV RNA for genotypes 3 and 4 in *S. scrofa* populations of Japan and several European countries, with seroprevalences of up to 43% (de Deus et al., 2008). One study in France (Kaba et al., 2010) compared the HEV genetic sequences of infected *S. scrofa* liver samples with human disease cases and found an 80 to 98% similarity between them. Consequently, research has suggested that *S. scrofa* may be a reservoir of HEV infection to humans primarily though foodborne transmission (Kaci et al., 2008; Michitaka et al., 2007). Research has also considered whether hunters also risk infection from contact with faeces (Meng et al., 2009) or direct exposure to blood during butchering (Kaba et al., 2010), as indicated in Table 6. The recent identification of novel HEV genotypes in *S. scrofa* from Japan (Sato et al., 2011) is concerning and requires further assessment of their zoonotic potential. Although Hepatitis E has yet to be identified in wild pig populations in Malaysia, its high seroprevalence in swine elsewhere increases suspicion for its presence here.

Bacteria

Wild pigs harbour many potentially zoonotic bacteria (with 12 listed in Table 4) and some examples of those causing serious human disease will be discussed.

Brucella

Brucella infection in humans may often cause debilitating influenza-like symptoms and although *Brucella suis* has been identified in many *S. scrofa* populations worldwide, some biotype strains are considered to be more pathogenic to people than others (Godfroid et al., 2011). Serological surveys of *S. scrofa* in Europe (see Table A2) have shown relatively high seroprevalences of *B. suis* biovar 2, particularly in Germany (Al Dahouk et al., 2005) and Croatia (Cvetnic et al., 2003), but the lack of documented brucellosis cases in European hunters has suggested it is less pathogenic than other biovars. One reported *B. suis* biovar 2 infection from France indicated that the hunter was already immune compromised (Garin-Bastuji et al., 2006), which could have increased his susceptibility. By contrast, *B. suis* biovars 1 & 3 have been identified in some *S. scrofa* populations from Australia and USA (Godfroid et al., 2005), with cases of brucellosis in American hunters (Giurgiutiu et al., 2009; Meng et al., 2009; Starnes et al., 2004) that were related to field-dressing carcasses without personal protective equipment. Human brucellosis has become a re-emerging disease in Australia due to the high prevalence of *B. suis* in feral *S. scrofa* populations and investigations into cross-species transmission (Eales et al., 2010; Irwin et al., 2010; Robson et al., 1993) have identified hunting as a major risk factor. Cases from Table A2 reported that the transmission of infection from wild pigs to humans has been associated with exposure to their bodily fluids or tissues and consumption of their meat (e.g. undercooked). The risks are increased if recommended health and safety precautions (e.g. disinfection procedures, wearing protective clothing and covering cuts) are disregarded (Massey et al., 2011). This evidence suggests that brucellosis may pose a significant health risk to Malaysians involved in the wild pig trade.

Enteric Bacteria

Several enteric bacteria found in wild pigs (shown in Table 4) may cause severe gastro-intestinal disease in humans.

Surveys of *S. scrofa* populations for STEC (from Table A2) have identified serotype O157: H7 in Germany (Schierack et al., 2009) and Spain (Sánchez et al., 2010) that suggests they could be reservoirs for human-pathogenic STEC strains. This theory has been supported by another study that found an 85 to 100% genetic similarity between STEC isolates from wild pig meat and human patients (Miko et al., 2009). The American STEC outbreak in 2006 highlighted the faeco-oral transmission risk of O157:H7 from feral pigs to humans (Jay et al., 2007) and so hunters may have increased transmission risk due to their direct contact with infected faeces. Foodborne STEC infections may occur from ingesting raw or undercooked contaminated meat (see Table 6). One European study reported that the coliform counts were higher from wild pig carcasses dressed in the field compared to those prepared under more hygienic abattoir conditions (Gill, 2007). This is of relevance to Malaysia where carcass preparation would commonly occur outdoors or in hunters' homes thus increasing the likelihood of STEC contamination.

Similarly, some human-pathogenic *Salmonella* species (e.g. *S. entertitis* & *S. typhimurium*) have been identified in *S. scrofa* populations from surveys in Europe, USA and Australia (references listed in Table A2). Table 6 indicates the importance of faeco-oral and foodborne transmission routes for *Salmonella* to humans and studies of processed *S. scrofa* carcasses in Australia (Bensink et al., 1991) and Japan (Kanai et al., 1997) have recovered significant numbers of

Salmonella serotypes. Consequently, salmonellosis may present a zoonotic hazard for hunters and consumers of wild pig meat in Malaysia.

Although *Campylobacter* species have been isolated from *S. scrofa* faecal samples in Spain (Carbonero et al., 2014; Navarro-Gonzalez et al., 2013), the data may not have been representative because these surveys were conducted in areas where the their population density was artificially high (e.g. hunting estates) that may have assisted the spread of infection. Surveys of wild pig populations for *Campylobacter* in forests and plantations of Malaysia would be beneficial to assess the public health risks.

Further information is required to understand whether *Yersinia enterocolitica* and *pseudotuberculosis* infection occurs in Malaysian wild pig species and whether these globally distributed pathogens have a higher prevalence in the temperate climates of Europe (Al Dahouk et al., 2005; Fredriksson-Ahomaa et al., 2009) and Japan (Hayashidani et al., 2002) compared to tropical Malaysia.

Parasites

Trichinella

Trichinella is the most important zoonotic parasite of swine and surveys of wild pig populations (see Table A3) have identified the different *Trichinella* species that they may harbour, e.g. *T. spiralis*, *T. nativa*, T. *papuae*, *T. britovi*, *T nelsoni* and *T. pseudospiralis* (Meng et al., 2009). Some *Trichinella* genotypes have specific geographic distributions (Pozio, 2007), but all *Trichinella* species use domestic or sylvatic hosts to maintain their life cycle and these factors lead to variations in the risk of human trichinellosis between regions (Pozio, 2000). Trichinellosis can occur from the ingestion of raw or undercooked meat containing encysted larvae, which can invade the small intestine causing gastrointestinal symptoms and systemic disease. Anthropogenic activities (e.g. hunting) can interfere with the epidemiology of sylvatic cycles causing humans to become aberrant hosts (Murrell and Pozio, 2000).

Trichinellosis outbreaks related to the consumption of wild pig meat have been reported in Europe (De Bruyne et al., 2006; Gołab and Sadkowska-Todys, 2005; Serrano et al., 1989), Asia (Cui et al., 2011; Jongwutiwes et al., 1998) , Africa (Pozio, 2007) and the Americas (Greenbloom et al., 1996; García et al., 2005), as shown in Table A3. These cases have often been associated with improper cooking, inadequate freezing (of non freeze-resistant *Trichinella* genotypes) or curing of the meat. In Southeast Asia, certain cultural food practices have increased the risk of *Trichinella* transmission from wild pigs, such as eating raw meat during festivals in Thailand (Kaewpitoon et al., 2008) and hunters undercooking meat on open fires in Papua New Guinea (Owen et al., 2005). One study identified 4 factors that influence trichinellosis disease risks (Kapel, 1997):

- Local hunting traditions;
- Prevalence and species composition of *Trichinella* populations;
- Veterinary hygiene at national pig farms;
- *Trichinella* diagnosis during meat inspection.

The list proposed by Kapel could be applied to Malaysia. Religious beliefs prevent the majority Muslim population from hunting wild pigs or rearing domestic pigs and so it may be less likely for *Trichinella* species (e.g. *T. spiralis*) hosted by domestic swine to be transmitted to wild pig populations. In addition, The Department of Veterinary Services inspects pig farms and abattoirs in order to provide a well-organised livestock disease control and prevention system (Mohd Nor et al., 2003), which may reduce domestic cycles of *Trichinella* infection. However, the butchering of wild pigs would commonly occur in rural locations without veterinary meat inspection preventing the identification of *Trichinella* diseased carcasses. From this information, perhaps it should be considered whether sylvatic cycle associated *Trichinella* genotypes may be more likely to be transmitted to wild pig consumers in Malaysia linked to improper human behaviour e.g. field-dressing techniques (Murrell and Pozio, 2000).

Others

Case reports from Asia have provided evidence for other parasitic diseases related to wild pig consumption including toxoplasmosis in Korea (Choi et al., 1997), sparganosis in Japan (Tanaka et al., 1997) and taeniasis in Taiwan (Fan et al., 1992), shown in Table A3.

3.4.2 Deer Species

The lack of scientific literature about the zoonotic pathogens carried by *M. muntjak* and *R. unicolor* has required the use of research from other *Cervidae* species in order to examine human health risks.

Viruses

Hepatitis E Virus

HEV has been found in *Cervus nippon* of Japan (Matsuura et al., 2007) and *Cervus elaphus* of the Netherlands (Rutjes et al., 2010). Direct evidence for transmission of HEV infection from deer to humans has been provided from cases in Japan (Table A1 provides references) and one study (Tei et al., 2003) used genetic sequencing to show that HEV in consumed venison was 99.7 to 100% identical to that found in infected patients, thus confirming foodborne transmission. Further research is necessary to determine whether human contact with HEV-infected deer tissues or faeces can lead to transmission of infection and whether HEV is present in Malaysian deer populations.

Parapoxvirus

The transcutaneous transmission of *Parapoxvirus* (see Table 6) should concern deer hunters who handle animals or carcasses because infection can cause chronic lesions to develop on hands (Tryland et al., 2001b). The transmission of *Parapoxvirus* infection via skin cuts and abrasions to deer hunters has been relatively rare (possibly due to under-reporting of this often self-limiting disease) and associated with field-dressing (Roess et al., 2010), skinning (Smith et al., 1991) or inspecting (Kuhl et al., 2003) deer. Investigations into *Parapoxvirus* infection of Malaysian hunters would be advisable because of the high numbers of *M. muntjak* and *R. unicolor* traded here.

Bacteria

Brucella

Cervidae species may also transmit pathogenic *Brucella* strains to hunters and venison consumers (described in Table 6). Surveys of wild deer populations have identified *Brucella* pathogens in various species (referenced in Table A2), with *B. abortus* being more commonly reported (Böhm et al., 2007) than *B. suis* infection (Forbes, 1991). Several references for human brucellosis infection from deer are provided in Table A2 and sporadic cases in native North American people have been associated with their hunting traditions (Tessaro, 1986). Human interference within ecosystems has led to some wildlife species becoming reservoirs for *Brucella* that can increase human infection risk e.g. *C. elaphus* populations in Greater Yellowstone, USA (Godfroid et al., 2005), but the epidemiology of *Brucella* in wildlife hosts within Southeast Asia is less understood due to a lack of data. A recent serological survey of wildlife at a rescue centre in South Korea (Kim et al., 2014) identified a high seroprevalence of *B. abortus* (59%) in *Hydropotes inermis* and future studies could help determine if this deer species is an infection reservoir. Surveys of free-ranging wild deer populations for *Brucella* are important in Malaysia because brucellosis is endemic within domestic livestock despite national veterinary eradication policies (Bamaiyi et al., 2012).

Mycobacterium bovis

The post mortem surveys listed in Table A2 show the wide variety of deer species infected by *Mycobacterium bovis*, including *M. muntjak* in India (Baviskar and Bhandarkar, 2010) that is also hunted in Malaysia. Tuberculosis may be regarded as a re-emerging infectious disease at the wildlife-human interface in some locations e.g. *M. bovis* has become endemic in some *Odocoileus virginianus* populations in Michigan, USA (Palmer et al., 2012). The occurrence of bovine tuberculosis in cattle and agriculture encroaching into forests in Malaysia may both influence *M. bovis* infection rates within deer populations, with zoonotic implications for hunters and consumers. The three major routes of infection are indicated in Table 6, with foodborne and transcutaneous being of greatest concern to humans involved in the wild meat trade. For consumers, ingestion of infected or contaminated venison and organs may cause chronic granulomatous tuberculosis (Wilkins et al., 2003). For deer hunters, the cutaneous exposure to *M. bovis* can occur via pre-existing wounds or accidental knife cuts during field-dressing (Wilkins et al., 2003) and the genotyping of *M. bovis* isolates from a deer carcass and hunter has provided evidence for cross-species transmission via a contaminated hunting knife (Wilkins et al., 2008). Although the inhalation of aerosolised *M. bovis* is a well-recognised occupational hazard for abattoir workers processing farmed deer (Liss et al., 1993; Nation et al., 1999), it may be unlikely to occur in wild deer hunters because they slaughter a smaller number of animals in the outdoors, which reduces build-up of aerosolised bacterial droplets (Wilkins et al., 2003).

Bacillus anthracis

Anthrax is a relatively rare disease of humans that is caused by *Bacillus anthracis* and has been found in some deer populations (referenced in Table A2). The most likely routes of human infection are transcutaneous and foodborne leading to different clinical manifestations of this potentially fatal disease (Fasanella et al., 2010). Cutaneous anthrax occurs when the bacteria enter broken skin through touching contaminated animal products (e.g. bone, hair and hide) and suspected cases related to contact with *C. elaphus* have been reported in Italy (Fasanella et al., 2007). Intestinal anthrax arises from the ingestion of contaminated meat. The combination of inadequate food safety controls and lack of wild meat inspection in developing countries may increase zoonotic risk, as highlighted by a confirmed venison-related outbreak in India (Ichhpujani et al., 2004).

Enteric Bacteria

Table A2 indicates that STEC, *Campylobacter*, *Salmonella* and *Yersinia* species have been identified in deer species and may lead to foodborne infections in humans. Several cases of human infection with STEC strains acquired from the consumption of venison have been reported in the USA (Keene et al., 1997; Rabatsky-Ehr et al., 2002; Rounds et al., 2012) and a detailed discussion of this specific food safety risk will be presented in Section 4. Although *Salmonella* species have been identified in surveys of free-ranging *Cervidae* species (referenced in Table A2), one review commented that *Salmonella* contamination of wild venison appeared to be uncommon from studies of hunter-killed deer carcasses in Europe, North America and New Zealand (Gill, 2007). Reports of human salmonellosis from deer have also been sporadic, such as the ingestion of raw venison sashimi causing gastroenteritis in Hawaii (Madar et al., 2012) and a Danish outbreak traced back to venison salami (Kuhn et al., 2011). Investigations are required in Malaysia to evaluate the risk of wild venison consumers acquiring enteric bacterial infections when compared with published cases from other countries.

<u>Parasites</u>

Toxoplasma

Toxoplasma gondii has been identified in some free-ranging deer species within regions where domestic cat populations are present, including the Canadian Arctic (Kutz et al., 2009) and Spain (Gamarra et al., 2008). The risk of toxoplasmosis from exposure to an oocyst-contaminated environment associated with cat ownership has been identified within some Malaysian ethnic groups (Yahaya, 1991). Increased cat ownership in Malaysia has led to greater numbers of free-roaming cats that could enable *T. gondii* infection to exist in wild deer populations, potentially causing zoonotic transmission to humans by the ingestion of infective tissue cysts or oocyst-contaminated venison (see Table 6). An epidemiological study in Canada identified that fur-skinning and consumption of raw or undercooked caribou meat had caused *T. gondii* infection of Innuit women (McDonald et al., 1990) and toxoplasmosis diagnosed in American deer hunters (Sacks et al., 1983; Ross et al., 2001) was associated with handling carcasses and eating venison.

Others

Other parasites that may infect wild deer hunters and consumers through foodborne or faeco-oral transmission are indicated in Table A3, including *Cryptosporidium*, *Giardia*, *Sarcocystis* and *Trichinella* species.

3.4.3 Reptile Species

There is well-documented evidence for the harbouring of zoonotic bacteria and parasites by reptiles from *Squamata, Testudine* and *Crocodylia* orders, as shown in Tables A2 and A3.

<u>Parasites</u>

Pentastomidia

Pentastomiasis is a serious zoonotic disease usually caused by *Armillifer* species from reptiles found in tropical and subtropical regions (Magnino et al., 2009), with human cases diagnosed in Africa (Yapo Ette et al., 2003) and Asia (Yao et al., 2008). Humans become aberrant hosts by acquiring infection from reptiles, particularly snakes and crocodiles, through the ingestion of infectious larvae (from raw or undercooked meat) or eggs (from contact with faecal-contaminated carcasses or respiratory secretions) (Magnino et al., 2009). Several python species indigenous to Malaysia, e.g. *P. reticulatus* (Latif et al., 2011) and *P. curtus* (Witchaya Tongtako 2013), have been identified as final hosts for human-pathogenic *A. moniliformis*. Pentastomiasis has been reported in aboriginal people of Peninsular and East Malaysia in relation to the traditional consumption of snake meat (Prathap et al., 1969; Latif et al., 2011) and some rural tribes may be at greater risk of infection due their cultural preference for undercooking this meat (Prathap et al., 1969). Other Pentastomidia families (e.g. *Sebekidae* and *Subtriquetridae*) have been identified in crocodile (Junker et al., 1999) and soft-shell terrapin species (Curran et al., 2014), but their lifecycles and zoonotic potential are less understood.

Sarcocystis

Sarcocystis species have been detected in faecal samples of wild and captive snake species in Malaysia (Lau et al., 2013), Germany (More et al., 2014) and the UK (Daszak and Cunningham, 1995), which are known to be definitive hosts for this parasite. The giant lizard, *Gallotia simonyi*, was found to harbour a *Sarcocystis* parasite (Bannert, 1992) thus increasing the suspicion that monitor lizards in Malaysia could also be definitive hosts (Tappe et al., 2013). Transmission from reptiles to humans may occur though the faeco-oral route (see Table 6) and one study of a sarcocystis outbreak in Malaysia (Lau et al., 2014) used generic sequencing to confirm the similarity of *S. nesbitti* between human cases and *Naja naja* species to supply evidence for this. Therefore, hunters butchering snakes or eating contaminated meat may risk *Sarcocystis* infection.

Spirometra and Gnathostoma

The highly complex lifecycles of *Spirometra* species require one definitive and two intermediate hosts for completion. The second intermediate host can be a reptile that becomes infected when it ingests a primary intermediate copepod host, leading to the development of the second larval stage (plerocercoids) within reptile tissues (Magnino et al., 2009). Human infection may occur from ingesting raw or undercooked meat containing plerocercoids (Anantaphruti et al., 2011) that can migrate through the body causing damage to tissues and organs. High numbers of plerocercoids have been identified in snake species (Sato et al., 1992) and human sparganosis cases have been traced back to the consumption of snakes (Magnino et al., 2009), with cases in Asia due to cultural preferences for eating raw snake meat e.g. Korea (Min, 1990) and Thailand (Anantaphruti et al., 2011; Wiwanitkit, 2005).

Similarly, gnathostomiasis may be caused by snake meat ingestion, with cutaneous or visceral larva migrans cases having been documented in Asia (Akahane et al., 1998, ; Seguchi et al., 1995). The identification of python and cobra meat in Malaysian establishments highlights the potential sparganosis and gnathostomiasis risk for consumers.

Trichinella

The threat of trichinellosis from reptiles should be considered as the new *Trichinella zimbabwensis* species was first found in Zimbabwean farmed *Crocodylus niloticus* during 1997 (Foggin et al., 1997) and since then natural infections have been discovered in *C. niloticus* and *Varanus varius* populations from Southern Africa (references in Table A3) probably linked to their scavenging behaviour. In Asia, a study identified novel *T. papuae* in 22% of wild-born *C. porosus* in Papua New Guinea (Pozio et al., 2004), which leads to the possibility that crocodiles in Malaysia could be carriers of an unidentified *Trichinella* species. The detection of novel *Trichinella* species in reptiles is of significance for consumers of crocodile or monitor lizard meat, particularly when foodborne trichinellosis outbreaks from reptiles have been documented in Thailand (Khamboonruang, 1991).

Bacteria

Salmonella

Potentially pathogenic *Salmonella* species (e.g. *S. enterica* serotypes) have commonly been found in the gastrointestinal tract of captive reptiles and shed in the faeces of pet iguanas (Burnham et al., 1998), freshwater turtles (Pasmans et al., 2002) and farmed crocodiles (Manolis et al., 1991). The public health risks from salmonellosis related to reptile pet ownership (Corrente et al., 2006; Harris et al., 2009) or zoos (Mitchell and Shane, 2001) have been well-recognised, with human infection primarily occurring via direct or indirect faeco-oral transmission (Diaz-Figueroa, 2008) and occasionally via transcutaneous transmission from scratches and bites. Reptile hunters may also risk salmonellosis because relatively high prevalences of zoonotic *Salmonella* isolates have now been identified in free-living chelonians (Hidalgo-Vila et al., 2007) and snakes (Kuroki et al., 2013) from Spain and Japan respectively. Foodborne salmonellosis has occurred from reptile consumption that included snapping turtles in Japan (Fukushima et al., 2008) and raw dried rattlesnake meat in USA (Bhatt et al., 1989; Kelly et al., 1995). The research has highlighted the potential risk of salmonellosis from wild reptiles and investigations of live animals and carcasses traded in Malaysia are necessary to determine whether they harbour zoonotic *Salmonella* serotypes.

Campylobacter

Some potentially zoonotic *Campylobacter* species (e.g. *C. fetus*) have been identified in faecal surveys of captive and wild reptiles (Gilbert et al., 2014; Wang et al., 2013b), with the highest prevalence in *Testudines*. The importance of free-living reptiles as *Campylobacter* reservoirs may vary between geographic regions, as indicated by the deficiency of this pathogen in turtles from one Spanish study (Marin et al., 2013). Therefore, targeted surveys of wild reptile populations in Malaysia would be advisable. Two recent investigations have isolated *C. fetus* subspecies of reptile origin from humans (see Table A2), the first identified it in nine people of Asian ethnicity (Patrick et al., 2013) and the second isolated it from an immunosuppressed patient who had eaten turtle soup (Tu et al., 2004b), which raise concerns for foodborne *Campylobacter* infection from reptiles.

3.4.4 Flying-Fox Species

Viruses

Some newly emerging, viral pathogens have been documented in flying-fox species found in Malaysia (*P. hypomelanus* and *P.vampyrus*) including *Nipah*, *Melaka* and *Pulau viruses* (shown in Table A1).

Nipah Virus

The *Nipah virus* outbreak in Peninsular Malaysia between 1998 and 1999 was caused by cross-species transmission from flying-fox to pig to human hosts and led to 265 reported human cases (Breed et al., 2006). There is evidence that flying-foxes are the natural reservoir hosts for *Nipah virus* in Malaysia as one survey found 25% of examined *P. vampyrus* and *P. hypomelanus* had neutralizing antibodies to *Nipah virus* (Yob et al., 2001) and another survey of *P. hypomelanus* on Tioman Island isolated the virus from their urine (Chua et al., 2002). Direct transmission of *Nipah virus* from flying-foxes to humans may be possible because epidemics have been reported in Bangladesh since 2001 in relation to flying-fox exposure without the involvement of livestock amplifier hosts (Luby et al., 2009). A wildlife survey has also identified antibodies to *Nipah virus* in *Pteropus giganteus* (Hsu et al., 2004) which is widely distributed in Bangladesh (Luby et al., 2009). The geographic concentration of human cases in Bangladesh could be related to seasonal exposure to *P. giganteus* populations (attracted by fruit availability) and may lead to contact with *Nipah virus* infected flying-fox urine or saliva (Luby et al., 2009). Since one disease outbreak was associated with the consumption of raw date palm sap contaminated with their excretions (Luby et al., 2006), it should also be considered whether flying-fox consumers could ingest *Nipah virus* from meat contaminated with saliva or urine. The epidemiology of *Nipah virus* spillover events directly from *Pteropodidae* species to humans should alert hunters to the potential zoonotic risks from contact with *Pteropus* species. A study in Indonesia has already identified the substantial risk of zoonotic infection for *Pteropus* hunters and traders due to the lack of personal protection against their bites and scratches (Harrison et al., 2011), this should also be investigated in Malaysia.

Reoviruses

Some new *Reoviridae* (respiratory enteric orphan viruses) have recently been identified in *Pteropodidae* and humans in Malaysia that may have zoonotic significance. A novel *Orthoreovirus* was discovered in pooled urine samples collected from a *P. hypomelanus* colony on Tioman Island and genetic sequence analysis characterised it as *Pulau virus* (Pritchard et al., 2006). The subsequent isolation of *Melaka virus* (another *Orthoreovirus* genetically similar to *Pulau virus*) from a person suffering with fever and respiratory illness has indicated potential *Orthoreoviridae* pathogenicity to humans (Chua et al., 2007). This epidemiological investigation revealed the patient’s exposure to a bat in his house thus implicating zoonotic virus cross-species transmission. Further investigations should examine whether close contact with *Pteropus* species could lead to human *Orthoreovirus* infections, as highlighted in Table 6.

3.5 Summary

The literature review cannot provide a detailed discussion on all the potential zoonotic infections from wildlife traded for wild meat. Instead, it has focused on highlighting the key pathogens from the most commonly available species in Malaysia in order to consider potential transmission routes and disease risks to humans, based upon an assessment of the evidence documented in the appendix. The review illustrates the huge range of possible zoonotic pathogens (including 16 viruses, 19 bacteria and 16 parasites) from the great variety of hunted wildlife. In particular, wild ungulates and reptiles pose many bacterial and parasitic disease risks to hunters and consumers, whilst flying-foxes and macaques host numerous zoonotic viruses. However, insufficient knowledge of the pathogens infecting some taxa (e.g. *Hystricidae* and *Manidae* species) may under-estimate the zoonotic risks to humans. This review suggests that further research is required into zoonotic infections of wildlife and humans in Malaysia of relevance to the wild meat trade.

4. Proposal for a Microbial Food Safety Risk Assessment

4.1 Introduction

A microbial food safety risk assessment identifies and estimates the probability of adverse health effects arising from the consumption of foods potentially contaminated by microbial pathogens or toxins (Lammerding and Fazil, 2000). The risk assessment methodology described here follows the Codex Alimentarius Commission (CAC) framework that is an internationally recognised system utilised in food safety procedures worldwide. It involves four steps of hazard identification, hazard characterisation, exposure assessment and risk characterisation to produce a final risk estimate (CAC, 1999), which indicates the magnitude of risk to the public associated with the microbial hazard in the food. The effects of uncertainty (limitations in data or knowledge) and variability (inherent heterogeneity or diversity of data) should be considered for all stages of the process (Lammerding and Fazil, 2000).

4.2 Qualitative risk assessment approach

4.2.1 Objective

To conduct a food safety risk assessment in order to evaluate the consumer risk for Shiga toxin-producing *Escherichia coli* (STEC) from the consumption of wild deer in Malaysia.

4.2.2 Context

Scientific evidence has indicated that STEC infections have been a major cause of foodborne illness in Europe (EFSA, 2011). The STEC serotypes are described by the O (the polysaccharide part of the cell wall lipopolysaccharide) and H (the flagella protein) antigens with the O157:H7 serotype being the most common cause of STEC disease outbreaks in the USA and Europe (Eggert et al., 2013). The involvement of pathogenic non-O157 STEC serotypes (e.g. O26, O45, O103, O111, O121 and O145) in human disease may have been under-estimated due to lack of awareness and appropriate culturing methods (Eggert et al., 2013).

Recent studies have isolated several STEC serotypes from deer (referenced in Table A2) that may pose a significant hazard to public health. The consumption of wild venison has been associated with transmission of O157:H7 infection to humans both in the USA (Keene et al., 1997; Rabatsky-Ehr et al., 2002) and Japan (Nagano et al., 2004) and handling venison has led to O103:H2 infection in schoolchildren (Rounds et al., 2012). Although STEC contamination of deer carcasses most frequently occurs during slaughtering and butchering (Membré et al., 2011), it may happen at any stage of the venison production chain due to inadequate sanitation and hygiene practices (García-Sánchez et al., 2007).

Faecal-sampling surveys of wild deer species in Spain (García-Sánchez et al., 2007) and USA (Renter et al., 2001) have identified a variable prevalence of infection for O157:H7 and more recent surveys have isolated potentially zoonotic non-O157 serotypes (e.g. O146 & O8) at relatively high frequencies from deer faeces and/or lymphatic tissues (Sánchez et al., 2009; Eggert et al., 2013), as shown in Table A2. Consequently, some studies (Avagnina et al., 2012; Obwegeser et al., 2012; Atanassova et al., 2008) have investigated the hygienic quality of wild deer carcasses by sampling them for total aerobic counts, *Enterobacteriaceae* counts (a faecal contamination indicator) and the prevalence of STEC bacteria; relatively high microbial counts were observed in some cases. Furthermore, one investigation found that O103:H2 and O26:H11 serotypes in wild venison were genetically similar to STEC isolates of the same pathogenic strains from human patients (Miko et al., 2009). These studies suggest that asymptomatic wild deer species may be important STEC reservoirs and faecal-contaminated deer carcasses should be considered a potential infection risk for venison consumers (García-Sánchez et al., 2007).

The literature has demonstrated the importance of understanding the epidemiology of food-borne STEC infections from wild deer, which is relevant to Malaysia as this dissertation has shown broad availability of venison in wild meat establishments. Therefore, this section will propose how to conduct a food safety risk assessment for this hazard in Malaysia and will indicate where further scientific research and expert opinion is required.

4.2.3 Method

A qualitative risk assessment would be the first step in evaluating this potential food safety issue in Malaysia and the framework shown in Figure 11 (CAC, 1999) would be followed.

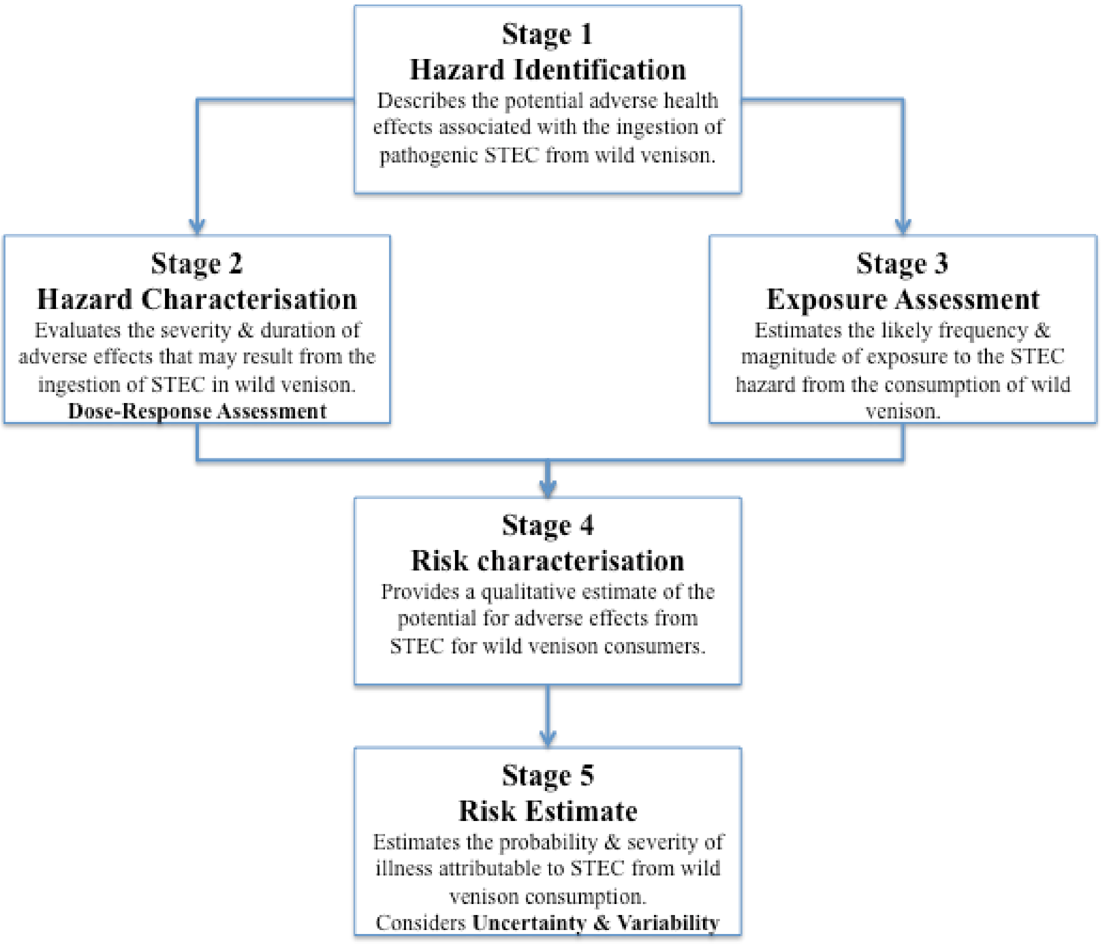


Figure 11: Steps in the qualitative risk assessment

4.3 Stage 1: Hazard Identification

Pathogenic STEC O157 and non-O157 serotypes can infect people through the ingestion of bacteria from faecal-contaminated food, leading to the absorption of Shiga toxin from the gut which may damage vascular endothelial cells potentially causing three disease syndromes (Mihajlovic et al., 2013), described in Table 7. The variations in disease severity and frequency associated with different serotypes led to the proposal for STEC classification into 5 seropathotypes from A to E, the most virulent being A which includes O157:H7 (Gyles, 2007).

Table 7: Clinical disease syndromes related to STEC infections

Disease syndrome	Clinical effects	Incubation period (days)	Humans at risk	Overall mortality rate
Haemorrhagic colitis (HC)	Acute onset severe abdominal pain, progression from watery to bloody diarrhoea, commonly nausea & vomiting, possible mild fever.	2-10 (Average 3-4)	Humans of any age, but increased risk for children, the elderly and immuno-compromised people.	Extremely low unless progresses to HUS or TPP*
Haemolytic uraemic syndrome (HUS)	Develops in 5-10% of O157:H7 infections. Acute renal failure, haemolytic anaemia, low platelet count.	HUS can develop on average 7 days after the first symptoms of infection.	Children under 5 years.	2-7% *
Thrombotic thrombocytopenic purpura (TPP)	Occurs infrequently. Renal failure, haemolytic anaemia, low platelet count, but also central nervous system involvement and fever. More chronic effects.		The elderly	Up to 50% in elderly*

(CDC, 2014; FDH, Florida Department of Health, 2012) * For O157:H7 (Mihajlovic et al., 2013)

The case reports referenced in Table 8 have provided epidemiological data about the faeco-oral transmission of STEC infection to humans from direct or indirect exposure to deer faeces. They have highlighted the risks from handling or consuming contaminated venison meat and products, especially if improperly cooked. Table 8 indicates that whilst O157:H7 has most commonly caused sporadic infections in venison consumers, the pathogenic significance of other non-0157 serotypes in deer should also be considered.

This risk assessment would require epidemiological information about STEC serotypes identified in wild deer species and humans in Malaysia. The Ministry of Health would need to conduct disease surveillance studies and outbreak investigations to assess the zoonotic risks, particularly focusing on people involved in the wild meat trade, whilst The Department of Veterinary Services would need to perform surveys of wild deer populations to assess the prevalence of STEC infections.

Table 8: Case reports of STEC infections associated with deer consumption

Reference & location	STEC strain isolated	Source of infection	Number of human cases	Clinical disease	Mortality rate	Identified transmission risks
(Keene et al., 1997) Oregon, USA.	O157:H7	Homemade jerky venison from *Odocoileus hemionus*.	6 confirmed & 5 presumptive in adults & children.	HC	0%	Low-temperature dehydration of contaminated venison did not eradicate STEC prior to its consumption.
(Rabatsky-Ehr et al., 2002) Connecticut, USA.	O157:H7	Undercooked grilled venison from *Odocoileus virginianus.*	1 confirmed case in 7-year old child.	HC	0%	Significant contamination of deer carcass related to shooting and processing. Large quantity of undercooked venison was eaten
(Rounds et al., 2012) Minnesota, USA.	O103:H2	Raw & undercooked grilled venison from *Odocoileus virginianus.*	6 confirmed & 23 presumptive in children.	HC	0%	Consumption of undercooked or pink venison. Cross-contamination from raw to cooked venison. Poor hygiene when handling contaminated raw venison.
(Nagano et al., 2004) Hokkaido, Japan	O157:H7	Cooked venison, deer species not given.	1 confirmed infection in adult female	Asymptomatic	Not applicable	Not provided, no information about cooking method.

4.4 Stage 2: Hazard Characterisation

This stage is described in Figure 11; it requires a dose-response assessment in order to determine the relationship between the magnitude of exposure and the magnitude, frequency and duration of adverse effects due to the presence of the STEC in venison (CAC, 1999). Sources of data would be provided by STEC-disease outbreak investigations and experimental studies, but not human-volunteer-feeding studies due to this disease being potentially life threatening.

The dose-response assessment examines the interaction between:

- Microbial pathogen effects;
- Host effects;
- Food matrix effects.

(Buchanan et al., 2000)

4.4.1 Microbial pathogen effects

The examination of STEC effects include:

- Its mode of pathogenicity;
- Its virulence characteristics;
- The measurement of biological responses;
- The relationship between the number of cells ingested and the severity of disease.

(Buchanan et al., 2000)

The pathogenicity of STEC is toxico-infectious because disease involves intestinal colonisation with subsequent toxin damage. The acid-tolerance of STEC (Mihajlovic et al., 2013) enables their survival in the stomach for entry into the intestinal tract, which activates virulence genes to produce specific virulence factors (examples listed in Table 9) that cause a series of damaging cellular events leading to clinical disease (Gyles, 2007). The virulence of different serotypes depends upon their production of specific virulence factors e.g. Stx2 and Intimin are most important for O157:H7 (Law, 2000).

Table 9: STEC Virulence factors

Virulence Factor	Function
Shiga toxins: Stx1, Stx2 & variants	Damages intestinal epithelial and renal endovascular cells, involved in the development of HC & HUS.
Intimin	Mediates attaching and effacing onto intestinal epithelial cells.
Extracellular serine protease	It may cleave human coagulation factor V, decreasing the coagulation reaction.
Enterohaemolysin	Function unclear, could cause haemolysis

(Law, 2000)

The biological response will be determined by morbidity and mortality rates (defined in Table 10) from STEC disease outbreaks for specific serotypes found within different countries. Improved disease surveillance and reporting of STEC infections would be necessary in Malaysia for the calculation of these rates to facilitate a risk assessment.

Table 10: Biological response definitions

Morbidity Rate	The proportion of people in a population that develops clinical disease attributable to a specific agent over a defined period of time. Expressed for a given year per given unit of population.
Mortality Rate	The proportion of people in a defined population who die due to a specific agent over a defined period of time. Expressed in units of death per 1000 individuals per year.

(Wobeser, 2006)

Research has indicated that the infectious dose for humans varies between STEC serotypes and it is estimated to be between 20 and 700 organisms for O157:H7 (Law, 2000). Further case reports of STEC outbreaks associated with venison consumption would be useful to calculate the infectious dose for deer-related serotypes.

4.4.2 Host effects

Variation in susceptibility to STEC infections has been identified in human populations, e.g. young children, the elderly and immuno-compromised individuals are particularly susceptible to O157:H7 infections and have increased risk of developing HUS or TPP (García-Sánchez et al., 2007). Other individual host susceptibility factors linked to nutritional status, health status and concurrent infections should also be evaluated (CAC, 1999) for the STEC hazard from wild venison.

4.4.3 Food matrix effects

This considers the physical characteristics of the food and its effects on STEC pathogenicity (Buchanan et al., 2000) and should be examined for venison meat and products available in Malaysia.

4.5 Stage 3: Exposure Assessment

This would estimate the likelihood and magnitude of exposure to the STEC hazard from wild venison meat consumption (CAC, 1999), and would utilise data from Malaysia in models and assumptions to produce quantitative estimates of the amount of STEC ingested by an individual at random (per meal portion size) in the at-risk population (Lammerding and Fazil, 2000).

Bacterial pathogens have dynamic populations in food matrices and the following factors should be examined:

- STEC pathogen characteristics;
- STEC contamination of the deer carcass during the kill;
- STEC risks from the evisceration, processing, transport, storage and distribution of wild deer;
- Food hygiene during the preparation of wild venison;
- Patterns of wild venison consumption.

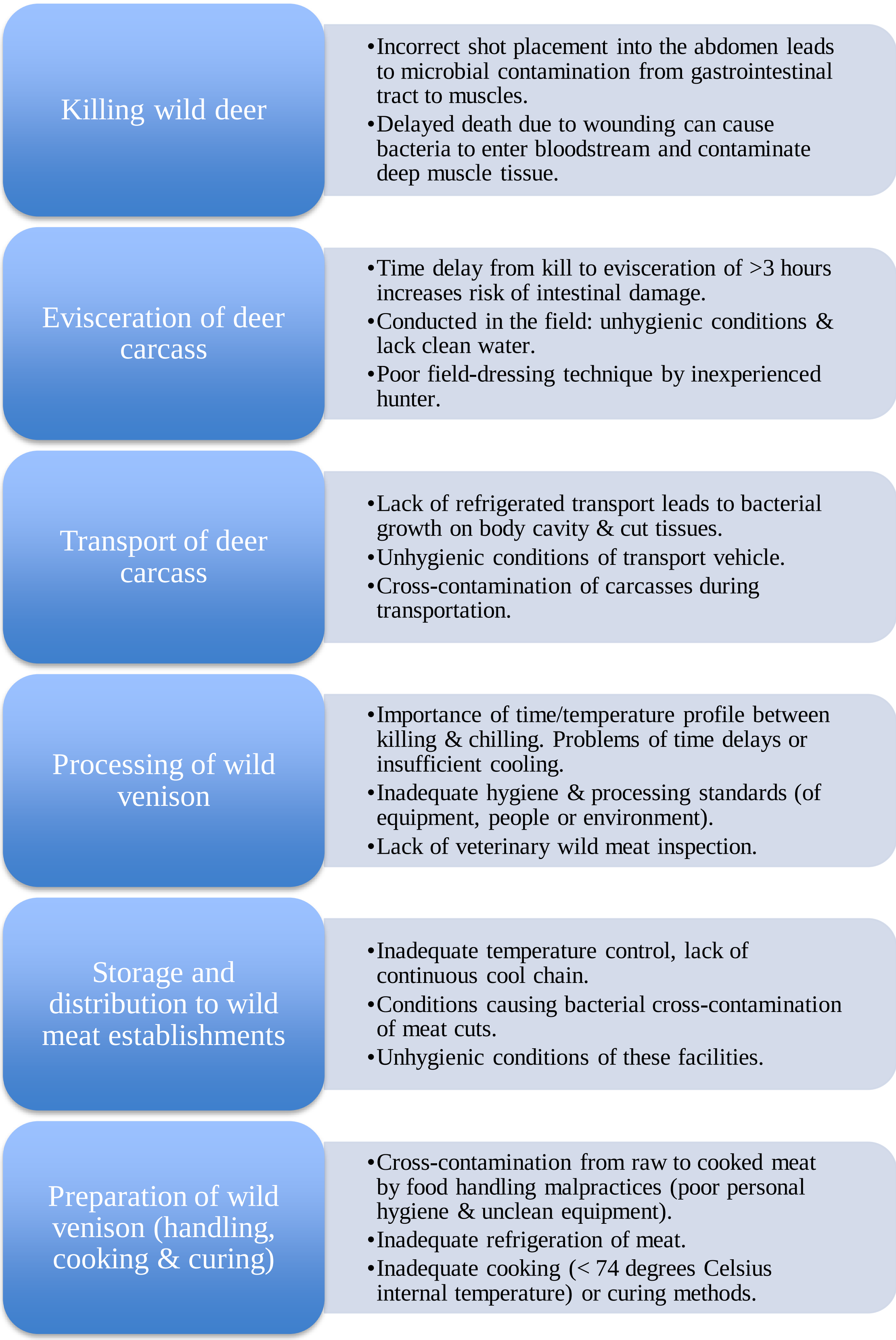
(Lammerding and Fazil, 2000)

4.5.1 Pathogen characteristics

Although the pathogenicity, virulence and toxic effects of STEC have already been discussed (sections 4.3 and 4.4), further examination of the literature would be necessary to evaluate these bacteria and their toxins in order to understand their growth and/or inactivation within the venison food product.

4.5.2 The wild venison production chain

Research in Europe has identified the potential risk factors for STEC contamination and growth on deer carcasses for each production stage (shown in Figure 12) and these should be investigated for the wild venison trade in Malaysia.



(Gill, 2007; Paulsen, 2011; Radakovic and Fletcher, 2011)

Figure 12: Microbial risk factors for STEC in the wild venison production chain

Published literature has indicated that wild deer should be killed quickly and eviscerated correctly by experienced hunters in order to limit microbial contamination of carcasses (Gill, 2007; Paulsen, 2011), as presented in Figure 12. Therefore, information about deer-slaughtering practices in Malaysia from field-based surveys would be required to assess STEC risk factors. Investigations would be necessary to determine whether temperature control occurs in the Malaysian venison production chain because the time/temperature profile from killing to cooling affects carcass contamination (Gill, 2007). Inspections of the locations and people associated with the wild venison trade should be conducted in Malaysia to examine the environmental conditions (Paulsen, 2011), hygienic quality of carcasses (discussed in section 4.2.2.) and food-handling practices (Radakovic and Fletcher, 2011). The process described in Figure 12 would most likely occur in uncontrolled and unsanitary conditions within a tropical climate, thus increasing the STEC risk.

4.5.3 Consumption patterns

Although some research has examined consumer behaviour in Malaysia (see section 2.3.1), interview and meal-based surveys would be required to collect qualitative information on the cultural factors relating to wild venison consumption and quantitative data about typical venison serving sizes and consumption rates.

4.5.4 Exposure assessment model

The recommended research would provide data for incorporation into an "exposure assessment model" (Membré et al., 2011) to decide whether the deer-related STEC hazard is a public health issue in Malaysia and would also depend upon expert advice from scientists and health professionals (Lammerding and Fazil, 2000).

4.6 Stage 4: Risk Characterisation

The risk characterisation would integrate the information from the previous stages to estimate the potential for adverse effects from STEC infection related to wild venison consumption in Malaysia (CAC, 1999). It would also evaluate the level of confidence in the final estimation of risk by considering the effects of variability and uncertainty (Buchanan et al., 2000). This stage would depend upon the availability of appropriate data and expert judgements during the time at which the risk assessment is conducted (CAC, 1999).

4.7 Stage 5: Risk Estimate

The risk estimate is defined in Figure 11. The risk characterisation would generate categorical descriptions for the risk estimates that could be defined by qualitative measures of the STEC-disease likelihood and impact on the population at risk, shown in Tables 11 and 12.

Table 11: Scoring system for the qualitative measures of likelihood

Score	Score definition	Description
1	Negligible	Too rare to merit consideration
2	Very low	Unlikely to occur
3	Low	Rare, but may occur occasionally
4	Medium	Occurs regularly
5	High	Occurs very regularly
6	Very high	It is almost certain to occur

(EFSA, 2006)

Table 12: Scoring system for the qualitative measures of disease impact

Score	Score definition	Description
1	Insignificant	Insignificant impact.
2	Minor	Minor impact for a small section of the venison consuming population.
3	Moderate	Minor impact for a large section of the venison consuming population.
4	Major	Major impact for a small section of the venison consuming population.
5	Catastrophic	Major impact for a large section of the venison consuming population.

(FAO, 2003.)

The risk assessment would clearly present the decision-making process for risk estimates using a tabular format, illustrated in Table 13.

Table 13: Example of risk estimate presentation

Describe the step being estimated	
Data available	**Risk estimate and conclusions**
Provide data & references	Discuss conclusions & provide qualitative measures for risk estimate

(FAO, 2003.)

The final outcome would be a written report presenting a comprehensive and systematic record of the qualitative risk assessment (Voysey and Brown, 2000).

4.8 Summary

This dissertation suggests that the popularity of wild venison consumption in Malaysia may pose significant STEC risks to humans because of the high likelihood that indigenous deer harbour these bacteria in combination with the unregulated and unsanitary conditions of the venison production chain. Further scientific research and improved disease surveillance of STEC infections in humans and wildlife would be required to successfully conduct this proposed risk assessment, including:

- Field surveys to determine STEC serotype prevalences in wild deer;
- Surveys of deer carcasses/meat cuts for microbial analysis;
- Investigations of locations involved in the wild venison production chain;
- Disease surveillance, epidemiological investigations and case reports for STEC-associated illness, focusing on deer hunters and consumers;
- Interview and meal-based surveys of deer hunters, traders and consumers.

5. Conclusions

5.1 Overall summary

This dissertation has been undertaken in order to better understand the drivers and impacts of the wild meat trade in Malaysia and determine the potential zoonotic disease risks to humans involved in it. It has suggested that the popularity of wildlife consumption drives a highly commercial trade, which represents a significant threat to many wild animal populations. Furthermore, this trade poses zoonotic infection risks to hunters, traders and consumers who are exposed to numerous pathogens from wildlife hosts and therefore it should be considered a public health issue requiring further investigation in Malaysia. The combined knowledge about the effects of the wild meat trade on wild animal populations and the potential zoonotic disease risks could help define wildlife conservation strategies that also benefit public health.

Over 22 species from 16 taxonomic orders or families have been identified in the TRAFFIC survey of wild meat establishments upon which the dissertation is based, which highlights the great diversity of wildlife traded for food and some taxa appear to be commonly available e.g. wild pigs, deer and reptiles. Many of the surveyed species have already been placed on the IUCN Red List as hunting is a recognised threat to their populations in Malaysia, but this dissertation has suggested that the impacts of the wild meat trade may be under-estimated for some species due to insufficient data. Whilst the cultural traditions of indigenous people favour wildlife consumption, an examination of the literature has identified that the majority of hunting in Malaysia now supplies consumers with wild meat as a luxury food through its commercial trade. The analysis of survey data combined with assessments on hunting threat levels to species has illustrated the significant effects of this trade on many wild animal populations in Malaysia and could assist in raising the profile of this exploitation issue.

This dissertation has also indicated that this trade may present significant public health risks as the literature review identified many potentially zoonotic pathogens in harvested wildlife, including 16 viruses, 19 bacteria and 16 parasites. It has examined the various transmission routes of infection to humans related to wildlife hunting, butchering and consumption for each pathogen. The detailed examination of the most commonly traded taxa (wild pigs, deer and reptiles) has suggested that they may present several disease risks to humans, particularly associated with the ingestion of wild meat (e.g. *Hepatitis E virus*, *Trichinella* parasites). Additionally, the review has examined some EIDs relevant to Malaysia in its discussion of *Nipah virus* and novel *Reovirus* transmission from flying-foxes to humans, which highlights the importance of zoonotic disease surveillance.

This comprehensive assessment of zoonotic pathogen information could be utilised by conservation professionals to dissuade people from harvesting wildlife for food due to the possible infection risks. For this reason, a wild meat food safety risk assessment has been proposed and discussed, which is dependent upon further epidemiological surveys of human and wildlife populations in Malaysia.

5.2 Summary of conclusions

5.2.1 Analysis of TRAFFIC report data

Wild meat availability

- The most commonly available wildlife traded for meat are wild pig species (*S. barbatus* and *S. scrofa*) and secondly deer species (*M. muntjak* and *R. unicolor*).
- Reptile species from *Squamata, Testudines* and *Crocodylia* orders are in third place.
- Smaller mammals including squirrels, civets and flying-foxes are commonly available.
- Wild bird meat is uncommon (only *G. gallus* identified) but whether this is an accurate representation of the trade is unknown.

Drivers of trade

- The majority of the Malaysian wild meat trade supplies commercial markets.
- Wild meat establishments supply consumers in both rural and urban areas.
- The meat from certain species is regarded as a delicacy (e.g. *M. muntjak*, *R. unicolor*, *C. sumatraensis*, *A. cartilaginea* and *D. subplana*) by some ethnicities.
- Species may be consumed for medicinal reasons (e.g. *A. cartilaginea*).
- Some indigenous Malaysian hunters still utilise wild meat for personal consumption.
- Some species are illegally exported to meet foreign demands for wild meat (e.g. *M. javanica*).

Impact of trade

- This trade may have significant impacts on some wild ungulate populations in Malaysia e.g. the IUCN Red List identifies hunting for meat as a major threat for *M. muntjak*, *R. unicolor*, *S. barbatus* and *C. sumatraensis* and research has suggested population declines for *R. unicolor* and *S. barbatus.*
- The impact of this trade on reptiles is less well understood because of uncertainty about the level of hunting threat and lack of population data for most species.
- Wild meat availability may be relatively uncommon for some species (e.g. *P. t. jacksoni* and *E. maximus*), but this trade could further endanger their survival because their estimated populations are small and hunting is a major threat.
- The lack of reliable population data (e.g. *C. sumatraensis, M. javanica*) and/or the uncertainty of the hunting threat (e.g. *A. cartilaginea*) and/or conflicting information (e.g. *P. vampyrus*) inhibit analysis of the impact that the wild meat trade has upon several species in Malaysia.

5.2.2 Zoonotic diseases literature review

Zoonotic viruses

- *Pteropodidae* and *Cercopithecidae* species appear to host the greatest number of viral pathogens and are relatively popular as wild meat, which is of zoonotic concern for wildlife hunters and consumers.
- *Pteropodidae* species in Southeast Asia may be reservoir hosts for some important viral EIDs (e.g. *Nipah virus*, *SARS Coronavirus* and novel *Reoviruses*).
- The genetic similarities between *Cercopithecidae* species and humans may risk cross-species transmission of viruses (e.g. *Cercopithecine herpesvirus-1*, *Simian foamy virus*, *Simian type D retrovirus*).
- Commonly hunted *Suidae* and *Cervidae* species can harbour *Hepatitis E virus*, which may cause foodborne human infections.

Zoonotic bacteria

- Several bacteria are commonly found in various wildlife hosts (e.g. *Brucella*, *Campylobacter*, *Leptospira*, *Salmonella*, *Yersinia* and *Mycobacterium* species), which may cause human infection via numerous transmission routes related to hunting, butchering and consumption.
- *Suidae* and *Cervidae* species host the greatest number of bacterial pathogens that may cause serious disease in humans (e.g. *STEC*, *Brucella* and *Mycobacterium* species).
- Reptiles can harbour gastro-intestinal pathogens, *Salmonella* and *Campylobacter*, with zoonotic transmission via foodborne and faeco-oral routes.

Zoonotic parasites

- Some parasites are commonly found in several wildlife hosts (e.g. *Cryptosporidium*, *Sarcocystis*, *Toxoplasma gondii and Trichinella* species), with zoonotic transmission via foodborne and/or faeco-oral routes.
- *Cercopithecidae* and *Suidae* species appear to harbour the greatest number of parasites. Since *Suidae* are the most commonly traded taxa and

Cercopithecidae have genetic similarity to humans, these factors may increase the likelihood of cross-species infection to humans.

- Reptiles pose some unusual zoonotic parasite risks (e.g. *Anisakidae, Gnathostoma,* and *Pentastomidia* species), which can cause foodborne infections in reptile consumers.

Exceptions

- Some wildlife species seem to host very few zoonotic pathogens, which may be a genuine possibility, but could be due to the lack of research into some species (e.g. *Hystricidae* and *Manidae*) that may under-estimate their zoonotic potential.

5.3 Further research

Further research is required to better understand the impacts of the wild meat trade on wildlife populations in Malaysia, for example:

- The dissertation has examined the first national survey of wild meat establishments in Malaysia, but additional long-term surveys would be recommended.
- Studies to obtain quantitative population data on listed species and determine harvesting rates in order to assess the level of hunting threat and its impacts on their populations.

The dissertation also indicates that improved zoonotic disease monitoring and surveillance of wildlife and humans in Malaysia would be beneficial in understanding the infection routes and risks related to the wild meat trade, for example:

- Epidemiological surveys (e.g. serological, faecal, post mortem) of wild animal populations for zoonotic pathogens.
- Epidemiological surveys of humans involved in the wild meat trade to find evidence for exposure to and infection with zoonotic pathogens.
- National measures to improve the investigation of human zoonotic disease cases.

- Interview surveys that examine wildlife hunting and consumption patterns in order to identify the zoonotic infection risks to humans.

A qualitative microbial food safety risk assessment is proposed for future research because global literature has suggested that the consumption of wild venison can cause STEC infection in humans. However, this risk needs to be evaluated in Malaysia and this would depend upon the collection of additional data, as discussed in Section 4. Whilst this specific food safety risk merits further investigation, there are a great number of other potential microbial hazards from wild meat consumption and the described risk assessment framework could also be applied to other zoonotic pathogens. The purpose of the proposed risk assessment is to illustrate the significance of the potential health risks associated with eating wildlife. It is hoped that this information could be utilised by conservation organisations to discourage this behaviour.

Appendix

Table A1: Potential zoonotic viral pathogens from wildlife involved in the wild meat trade

Legend: PCR= PCR testing, PM= post mortem examination, S= serology, V= virus isolation, G= genetic sequencing, O= other test.

WILDLIFE HOST		ZOONOTIC VIRUSES					
Animal class	**Taxonomic order or family**	**Viral pathogen**	**Scientific reference and country**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
Mammalia	Suidae	*Hepatitis E virus*	(de Deus et al., 2008) Spain; (Kaba et al., 2010) France; (Kaci et al., 2008) Germany; (Michitaka et al., 2007) & (Sato et al., 2011) Japan.	S of *Sus scrofa*; PM & PCR of *S. scrofa*; S of *S. scrofa*; S of *S. scrofa* for both.	Ingestion of undercooked or raw meat or liver. Faeco-oral transmission? (Meng et al., 2009) Direct contact with infected blood? (Kaba et al., 2010)	Consumption Hunting & Butchering? Butchering?	(Li et al., 2005b), (Masuda et al., 2005), (Matsuda et al., 2003) & (Toyoda et al., 2008) Japan; (Wichmann et al., 2008) Germany.
		Swine influenza virus	(Kaden et al., 2008) Germany; (Saliki et al., 1998) USA; (Vicente Baños et al., 2002) Spain.	S of *S. scrofa;* S of *S. scrofa;* S of *S. scrofa*.	Contact with infected respiratory secretions e.g. inhalation of aerosolised virus.	Hunting & Butchering	
Mammalia	Cervidae	*Hepatitis E virus*	(Matsuura et al., 2007) & (Tomiyama et al., 2009) Japan; (Rutjes et al., 2010) The	S of *Cervus nippon*; S of *C. nippon yesoensis*; S of *Cervus elaphus*.	Ingestion of undercooked or raw meat. Direct contact with	Consumption Hunting?	(Takahashi et al., 2004), (Tei et al., 2003) & (Tei et al., 2004) Japan.

WILDLIFE HOST		ZOONOTIC VIRUSES					
Animal class	**Taxonomic order or family**	**Viral pathogen**	**Scientific reference and country**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			Netherlands.		infected animals? (Teo, 2010)		
		Parapoxvirus	(Horner et al., 1987) New Zealand; (Klein and Tryland, 2005) Norway.	PM of farmed *C. elaphus*; PCR of *Rangifer terandus*.	Direct contact via damaged skin or wounds.	Hunting & Butchering	(Kuhl et al., 2003), (Roess et al., 2010) & (Smith et al., 1991) USA.
Mammalia	Sciuridae	*Lymphocytic choriomeningitis virus*	(Greenwood and Sanchez, 2002) UK.	S from PM *Sciurus carolinensis.*	Contact with infected excretions & secretions. Animal bite transmission.	Hunting & Butchering Hunting	
		Rabies (Lyssavirus	(Cappucci Jr et al., 1972) USA; (Webster et al., 1988) Canada.	PM of *Sciurus niger;* PM of unspecified squirrel species.	Animal bite transmission. Non-bite exposure from contact with infected saliva or tissues via mucous membranes or damaged skin.	Hunting Hunting & Butchering	(Kumari et al., 2014) India; (ProMED-mail, 2014b) Costa Rica.
Mammalia	Viverridae	*Highly Pathogenic Avian Influenza virus (e.g. H5N1)*	(ProMED-mail, 2005) & (ProMED-mail, 2008) Vietnam.	PM of captive *Chrotogale owstoni* for both.	Contact with infected respiratory secretions e.g. inhalation of aerosolised virus	Hunting & Butchering	

WILDLIFE HOST		ZOONOTIC VIRUSES					
Animal class	**Taxonomic order or family**	**Viral pathogen**	**Scientific reference and country**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		Rabies (Lyssavirus)	(Bingham, 1992) Zimbabwe; (de Fontes-Pereira et al., 2012) Angola; (Matsumoto et al., 2011) Sri Lanka; (Susetya et al., 2008) Indonesia; (ProMED-mail, 2014c) Taiwan.	PM of *Civettictis civetta*; PM of *C. civetta*; PM of *Paradoxus zeylonensis*; PCR from PM of unspecified civet; PM of *Paguma larvata taivana*.	Animal bite transmission. Non-bite exposure from contact with infected saliva or tissues via mucous membranes or damaged skin.	Hunting Hunting & Butchering	(ProMED-mail, 2009) Tanzania.
		SARS Coronavirus	(Guan et al., 2003), (Shi and Hu, 2008) (Tu et al., 2004a) China.	PCR from *Paguma larvata*; PCR from *P. larvata*; S of unspecified civets.	Contact with infectious respiratory droplets via mucous membranes. Indirect transmission via fomites.	Hunting & Butchering	(Bell et al., 2004), (Wang et al., 2005) & (Xu et al., 2004) China.
Mammalia	Caprinae	*Parapoxvirus*	(Inoshima et al., 1999), (Inoshima et al., 2001) & (Suzuki et al., 1993) Japan.	S of *Capricornis crispis* for all.	Direct contact via damaged skin or wounds.	Hunting & Butchering	
Mammalia	Pteropodidae	*Ebola virus e.g. Reston subtype*	(Olival et al., 2013) Bangladesh; (Taniguchi et al., 2011) Philippines.	S of *Rousettus leschenaultia*; S of *Rousettus amplexicaudatus*.	Fruit bats are likely reservoir hosts with transmission to human via an intermediate host.	Hunting & Butchering?	

WILDLIFE HOST		ZOONOTIC VIRUSES					
Animal class	**Taxonomic order or family**	**Viral pathogen**	**Scientific reference and country**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
					Could direct transmission from bat to human occur?		
		Lyssaviruses (including rabies)	(Arguin et al., 2002) The Philippines; (Baer and Smith, 1991) Thailand; (Reynes et al., 2004) Cambodia.	S of *Pteropus hypromelanus & R. amplexicaudatus*; S of *Cynopterus brachyotis*; S of PM *Cynopterus sphinx, Pteropus lylei & R. leschenaultia*.	Animal bites transmission. Non-bite exposure from contact with saliva or infected tissues via mucous membranes or damaged skin.	Hunting Hunting & Butchering	(Hanna et al., 2000), (Samaratunga et al., 1998), (Warrilow et al., 2002) & (ProMED-mail, 2014a) Australia.
		Nipah virus	(Chua et al., 2002), (Epstein et al., 2006) & (Yob et al., 2001) Malaysia; (Hsu et al., 2004) Bangladesh.	V & PCR of *P. hypromelanus*; S of *P.hypromelanus & Pteropus vampyrus*; S of *P.hypromelanus & P. vampyrus*; S of *P.giganteus*.	Ingestion of urine or saliva contaminated food products (could this include bat meat?) Contact with infected urine or saliva.	Consumption Hunting & Butchering	(Epstein et al., 2008) India; (Luby et al., 2006) & (Luby et al., 2009) Bangladesh.
		Reoviruruses (e.g. Melaka & Pulau virus)?	(Chua et al., 2007) & (Pritchard et al., 2006) Malaysia.	G of reovirus isolates from bats & humans; V & G of *P.*	Could direct transmission from bat to human occur through close	Hunting & Butchering?	(Chua et al., 2007) Malaysia.

WILDLIFE HOST		ZOONOTIC VIRUSES					
Animal class	**Taxonomic order or family**	**Viral pathogen**	**Scientific reference and country**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
				hypomelanus.	contact?		
		SARS Coronavirus	(Li et al., 2005c) China; (Müller et al., 2007) South Africa & Democratic Republic of Congo.	S of *R. leschenaultia*; S of *Rousettus aegyptiacus*.	Fruit bats are reservoir hosts with transmission to human via an intermediate host. Could direct transmission from bat to human occur?	Hunting & Butchering?	
Mammalia	Hystricidae	Not reported					
Mammalia	Ursidae	*Rabies (Lyssavirus)*	(Bronson et al., 2014) USA; (Mihai et al., 2006) Romania; (Prestrud et al., 1992) Norway; (Taylor et al., 1991) Canada.	S of *Ursus americanus*; PM of *Ursus arctos*; PM of *Ursus maritimus*; PM of *U. maritimus*.	Animal bite transmission. Non-bite exposure from contact with infected saliva or tissues via mucous membranes or damaged skin.	Hunting Hunting & Butchering	
Mammalia	Cercopithecidae	*Cercopithecine Herpesvirus*	(Huff and Barry, 2003) & (Weigler, 1992) both reviews; (Engel et al., 2002) Indonesia.	*S & PCR of Macaca genus (e.g. M. facicularis, M. artoides, M.*	Animal bite or scratch transmission. Non-bite exposure	Hunting Hunting &	(Holmes et al., 1990), (CDC, 1987), (CDC, 1998) & (Huff and

WILDLIFE HOST		ZOONOTIC VIRUSES					
Animal class	**Taxonomic order or family**	**Viral pathogen**	**Scientific reference and country**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
				nemestrina, M. fuscata, M. radiate, M. cyclopis); S of *M. fascicularis.*	from contact with infected saliva or secretions via mucous membranes or damaged skin. Respiratory transmission? (Weigler, 1992). Indirect transmission via contaminated fomites.	Butchering Hunting? Butchering	Barry, 2003) USA; (Weigler, 1992) USA & UK.
		Ebola virus Reston subtype	(Miranda et al., 1999) Philippines; (Rollin et al., 1999) USA.	S of captive *M. fascicularis*; S & V of captive *M. fascicularis.*	Contact with infected animals, body fluids & tissues.	Hunting & Butchering	(Miranda et al., 1999), (Morikawa et al., 2007) USA & Philippines.
		Rabies virus (Lyssavirus)	(Susetya et al., 2008) Indonesia; (Wilde et al., 1991) Thailand.	PM of unspecified monkey species; PM of *Macaca mulatta.*	Transmission from animal bites. Non-bite exposure from contact with infected animal saliva or tissues via mucous	Hunting Hunting & Butchering	(Favoretto et al., 2001) Brazil; (Summer et al., 2004) India.

WILDLIFE HOST		ZOONOTIC VIRUSES					
Animal class	**Taxonomic order or family**	**Viral pathogen**	**Scientific reference and country**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
					membranes or damaged skin.		
		Simian Foamy Virus	(Jones-Engel et al., 2006) Nepal; (Jones-Engel et al., 2007) Thailand & Singapore; (Leendertz et al., 2008) Cote d'Ivoire.	S of *M. mulatta*; S of *M. fascicularis*, *M. arctoides*, *M. mulatta/fascicularis* hybrid, *M. assamensis* & *M. nemestrina*; PCR of *Piliocolobus badius*.	Direct contact with infected saliva from bites, scratches and mucosal splashes.	Hunting & Butchering	(Brooks et al., 2002) Canada; (Huang et al., 2012) China; (Jones-Engel et al., 2005) Indonesia; (Jones-Engel et al., 2008) several Asian countries; (Schweizer et al., 1997) Germany; (Wolfe et al., 2004) Cameroon.
		Simian Type D Retrovirus (reported in captive macaques)	(Murphy et al., 2006) USA.	S & PCR of captive *Macaca genus*.	Direct contact with infected saliva from bites, scratches and mucosal splashes?	Hunting & Butchering?	(Lerche et al., 2001) USA.
		Simian Virus 40	(Butel and Lednicky, 1999) Asia; (Jones-Engel et al., 2006) Nepal.	S of Asian *Macaca species*; S of *M. mulatta*.	Direct contact with infected animal saliva from bites, scratches and mucosal splashes.	Hunting & Butchering	(Engels et al., 2004) North America; (Shah, 1972) India.

WILDLIFE HOST		ZOONOTIC VIRUSES					
Animal class	**Taxonomic order or family**	**Viral pathogen**	**Scientific reference and country**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
Mammalia	Felidae	*Highly Pathogenic Avian Influenza virus (e.g. H5N1)*	(Desvaux et al., 2009) Cambodia; (Keawcharoen et al., 2004) & (Thanawongnuwech et al., 2005) Thailand.	S of captive *Panthera tigris, Pantera leo, Panthera pardus, Catopuma temminckii & Neofelis nebulosa*; PM of *P. tigris & P. pardus*; PM of *P. tigris*	Contact with infected respiratory secretions e.g. inhalation of aerosolised virus (Reperant et al., 2009).	Hunting & Butchering	
		Rabies virus (Lyssavirus)	(Pandit, 1950) India; (Susetya et al., 2008) Indonesia; (Wilde et al., 1991) Thailand.	PM of *P. tigris*; PCR from PM of *P. tigris*; PM of *P. tigris*.	Animal bite transmission. Non-bite exposure from contact with infected saliva or tissues via mucous membranes or damaged skin.	Hunting Hunting & Butchering	(Pandit, 1950) India.
Mammalia	Manidae	Not reported					
Mammalia	Elephantidae	*Cowpox virus* (reported in captive elephants)	(Kik et al., 2009) The Netherlands; (Wisser et al., 2001) Germany.	PCR of captive *Elaphus maximus*; PM of captive *E. maximus*.	Direct contact via damaged skin, bites & scratches.	Hunting & butchering	(Hemmer et al., 2010) & (Kurth et al., 2008) Germany.
Reptilia	Squamata	Not reported					
Reptilia	Testudines	Not reported					

WILDLIFE HOST		ZOONOTIC VIRUSES					
Animal class	**Taxonomic order or family**	**Viral pathogen**	**Scientific reference and country**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
Reptilia	Crocodylia	Not reported					
Aves	Galliformes	*Avian paramyxovirus-1 (Newcastle disease)*	(Hopkins et al., 1990) USA; (Lee and Amin-Babjee, 1990) Malaysia; (Roy et al., 1998) India.	S of *Meleagridis gallopavo silvestris* PM of *Gallus* gallus; V of *G. gallus* &*Chrysolophus pictus*.	Contact with large amounts of virus from infected birds or their carcasses e.g. inhalation.	Hunting & Butchering	
		Highly Pathogenic Avian Influenza	(Desvaux et al., 2009) Cambodia; (Stallknecht et al., 2008) & (Swayne and Suarez, 2000) reviews.	V of *G. gallus*; V of *Phasianus colchicus* & *Alectoris graeca*; V of *Numida meleagris, Colinus virginianus, Phasianus colchicus, Coturnix japonica.*	Contact with infected respiratory secretions e.g. inhalation of aerosolised virus.	Hunting & Butchering	

Table A2: Potential zoonotic bacterial pathogens from wildlife involved in the wild meat trade

Legend: F= faecal sampling, PCR= PCR testing, PM= post mortem examination, S= serology, O= other test.

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
Mammalia	Suidae	*Bacillus anthracis*	(Bagamian et al., 2014) Ukraine; (Wafula et al., 2008) Uganda.	S of *Sus scrofa*; PM of *Phacochoerus africanus*.	Ingestion of raw or undercooked meat or tissues. Contact with contaminated animal products (e.g. fur, hide, bone) via broken skin. Inhalation of spores (rare).	Consumption Butchering Butchering	(ProMED-mail, 2011) India.
		Brucella spp	(Al Dahouk et al., 2005) Germany; (Cvetnic et al., 2003) Croatia; (Godfroid et al., 1994) Belgium; (Gresham et al., 2002) USA; (Irwin et al., 2010) Australia; (Watarai et al., 2006) Japan.	S of *S. scrofa* for all.	Ingestion of raw or undercooked meat or tissues. Direct contact with infected body fluids or tissues via broken skin or mucous membranes.	Consumption Hunting & Butchering	(Carrington et al., 2012), (Giurgiutiu et al., 2009) & (Starnes et al., 2004) USA; (Eales et al., 2010), (Massey et al., 2011) & (Robson et al., 1993)

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
							Australia; (Garin-Bastuji et al., 2006) France.
		Campylobacter spp	(Carbonero et al., 2014) & (Navarro-Gonzalez et al., 2013) Spain; (Jay and Wiscomb, 2008) USA.	F from *S. scrofa*; F from PM of *S. scrofa*; F from *S. scrofa.*	Ingestion of raw or undercooked meat or tissues. Faeco-oral transmission.	Consumption Hunting & Butchering	
		Chlamydophilia spp	(Hotzel et al., 2004) Germany; (Salinas et al., 2009) Spain.	PCR from PM of *S. scrofa*; S of *S. scrofa.*	Aerogenous or cutaneous transmission via infected secretions or excretions.	Hunting or Butchering	
		Erysipelothrix rhusiopathiae	(Risco et al., 2011) & (Vicente Baños et al., 2002) Spain.	PM of *S.* scrofa; S from PM of *S. scrofa.*	Ingestion of raw or undercooked meat (Kanai et al., 1997). Direct contact with animal products via damaged skin.	Consumption Butchering	(Addidle et al., 2009) New Zealand.
		Escherichia coli (Shiga toxin producing e.g. O157	(Jay et al., 2007) USA; (Sánchez et al., 2010) Spain; (Schierack et al.,	F of *S. scrofa*; PM of *S. scrofa*; F of *S. scrofa.*	Ingestion of raw or undercooked meat or tissues	Consumption	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		and others)	2009) Germany.		(Gill, 2007) & (Miko et al., 2009). Faecal-oral transmission.	 Hunting & Butchering	
		Francisella tularensis	(Al Dahouk et al., 2005) Germany; (Hubálek et al., 2002) Czech Republic.	S of *S. scrofa*; S from PM of *S. scrofa.*	Ingestion of raw or undercooked meat or tissues. Direct contact with infected animals via mucous membranes or broken skin. Inhalation of aerosolised bacteria.	Consumption Hunting & Butchering Butchering	(Deutz et al., 2002) Austria; (Esmaeili et al., 2014) Iran.
		Leptospira spp	(Ebani et al., 2003) Italy; (Jansen et al., 2007) Germany; (Saliki et al., 1998) USA; (Vicente Baños et al., 2002) Spain.	S of *S. scrofa*; S & PM of *S. scrofa*; S of *S. scrofa*; S of *S. scrofa.*	Ingestion of urine contaminated meat. Contact with infected urine or reproductive fluids via skin or mucous	Consumption Hunting & Butchering	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
					membranes.		
		Mycobacterium bovis	(Vicente et al., 2006) Spain; (Nugent et al., 2012) & (Wakelin and Churchman, 1991) New Zealand; (Zanella et al., 2008) France.	PM of *S. scrofa*; PM of *S. scrofa* for both; PM of *S. scrofa*.	Ingestion of raw or undercooked meat or tissues. Inhalation of aerosolised bacteria. Direct contact via damaged skin or wounds.	Consumption Hunting & Butchering Hunting & Butchering	
		Salmonella spp	(Bensink et al., 1991) & (Ward et al., 2013) Australia; (Thakur et al., 2011) USA; (Vengust et al., 2006) Slovenia; (Vicente et al., 2006) Spain; (Vieira-Pinto et al., 2011) Portugal.	PM of *S. scrofa* for both; F from PM of *S. scrofa*; S of *S. scrofa*; S from PM of *S. scrofa*; F of *S. scrofa*.	Ingestion of raw or undercooked meat or tissues (Kanai et al., 1997). Faecal-oral transmission.	Consumption Hunting & Butchering	
		Streptococcus suis	(Baums et al., 2007) Germany; (Higgins et al., 1997) Canada.	PM of *S. scrofa*; PM of *S. scrofa*.	Direct contact via damaged skin or wounds.	Hunting & Butchering	(Dalsjö et al., 2014) Sweden; (Halaby et al., 2000) The Netherlands; (Rosenkranz et

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
							al., 2003) Germany.
		Yersinia pseudotuberculosis (NB More likely in temperate rather than tropical climates) & *Y. enterocolitica*	(Al Dahouk et al., 2005) Germany; (Fredriksson-Ahomaa et al., 2009) Switzerland; (Hayashidani et al., 2002) Japan.	S of *S. scrofa;* PM of *S. scrofa;* PM of *S. scrofa*.	Ingestion of raw or undercooked meat or tissues.	Consumption	
Mammalia	Cervidae	*Bacillus anthracis*	(Fasanella et al., 2007) Italy; (Mehrotra et al., 2000) India; (Mongoh et al., 2008) USA;	PM of *Cervus elaphus*; PM of *Axis axis*; PCR of *Odocoileus virginianus & Cervus Canadensis*.	Ingestion of raw or undercooked meat or tissues. Contact with contaminated animal products (e.g. fur, hide, bone) via broken skin. Inhalation of spores (rare).	Consumption Butchering Butchering	(Ichhpujani et al., 2004) India; (ProMED-mail, 2001) USA; (Fasanella et al., 2007) Italy.
		Brucella spp	(Forbes, 1991) & (Tessaro, 1986) Canada; (Kim et al., 2014) South Korea; (Muñoz et al., 2010) Spain.	PM of *Rangifer tarandus* subspp, PM & S of *C. Canadensis*; S of *Hydropotes inermis* & introduced	Ingestion of raw or undercooked meat or tissues. Direct contact with infected	Consumption Hunting & Butchering	(Brody et al., 1966) Alaska, USA; (Chan et al., 1989) Arctic region; (Forbes,

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
				Capreolus capreolus; S of *C. Elaphus.*	body fluids or tissues via broken skin or mucous membranes.		1991) Canada; (Meyer, 1966) Alaska, Canada & Russia.
		Campylobacter spp	(Carbonero et al., 2014) Spain; (Khoshbakht et al., 2014) Iran.	F from *C. elpahus*; F from *Dama mesopotamica*	Ingestion raw or undercooked meat or tissues. Faeco-oral transmission.	Consumption Hunting & Butchering.	
		Chlamydophilia spp	(Cubero-Pablo et al., 2000) & (Salinas et al., 2009) Spain; (Di Francesco et al., 2012) Italy.	S of *C. elaphus & Dama dama*; S of *C. elaphus, D. dama & C. capreolus*; S of *C. elaphus.*	Aerogenous or cutaneous transmission via infected secretions or excretions.	Hunting & Butchering	
		Erysipelothrix rhusiopathiae	(Bruner et al., 1984) USA; (Eskens and Zschock, 1991) Germany.	PM of *O. virginianus;* PM of *C. capreolus.*	Ingestion of raw or undercooked meat (Kanai et al., 1997). Direct contact with animal products via damaged skin.	Consumption Butchering	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		Escherichia coli Shiga toxin producing (e.g. O157 & others)	(Asakura et al., 1998) Japan; (Eggert et al., 2013) Germany; (García-Sánchez et al., 2007) & (Sánchez et al., 2009) Spain; (Obwegeser et al., 2012) Switzerland; (Renter et al., 2001) USA.	F from unspecified wild deer; F and PM of *C. elaphus* & *C. capreolus*; PM of *C. elaphus*, *C. capreolus* & *D. dama* for both; F for PCR of *C. elaphus* & *C. capreolus*; F of *O. virginianus*.	Ingestion of raw or undercooked meat or tissues (Gill, 2007) & (Miko et al., 2009). Faecal-oral transmission.	Consumption Hunting & Butchering	(Keene et al., 1997), (Rabatsky-Ehr et al., 2002) & (Rounds et al., 2012) USA; (Nagano et al., 2004) Japan.
		Leptospirosis spp	(Ayanegui-Alcerreca et al., 2007) New Zealand; (Bender and Hall, 1996) USA; (Uhart et al., 2003) Argentina.	S & PM of *C. elaphus*, *Cervus nippon, D. dama, C. canadensis*; S of *C. canadensis*; S of *Ozotoceros bezoarticus celer*.	Ingestion of urine contaminated meat. Contact with infected urine via skin or mucous membranes.	Consumption Hunting or Butchering	(Bell, 2005) & (Brown, 2005) New Zealand.
		Mycobacterium bovis	(Baviskar and Bhandarkar, 2010) India; (Delahay et al., 2001) UK; (Pavlik et al., 2002) Czech Republic & Hungary; (Martín-Hernando et al., 2010) Spain; (Rhyan and Saari, 1995) & (Schmitt	PM of *Muntiacus muntjak*; PM of *M. muntjak*; PM of *C. elaphus*; PM of *C. elaphus elaphus*, *D. dama;* PM of *D. dama*, *C. nippon*, *C. elaphus elaphus*, *Cervus elpahus*	Ingestion of raw or undercooked meat or tissues. Inhalation of aerosolised bacteria. Direct contact via damaged skin or wounds.	Consumption Hunting & Butchering Hunting & Butchering	(Baker et al., 2006) New Zealand; (Fanning and Edwards, 1991), (Liss et al., 1993) & (Nation et al., 1999) Canada; (Wilkins et al.,

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			et al., 1997) USA.	*nelsoni*; PM of *O. virginianus.*			2003) (Wilkins et al., 2008) USA.
		Salmonella spp	(Aschfalk et al., 2002) Norway; (Branham et al., 2005) & (Renter et al., 2006) USA; (Sato et al., 2000) Japan.	S of *Alces alces*; PM of *O. virginianus*; F from *O. virginianus*; PM of *C. nippon.*	Ingestion of raw or undercooked meat or tissues. Faecal-oral transmission.	Consumption Hunting & Butchering	(Kuhn et al., 2011) Denmark; (Madar et al., 2012) Hawaii.
		Yersinia pestis	(ProMED-mail, 2003) USA.	PM of *O. hemionus*	Contact with infected secretions or tissues via bites, scratches, damaged skin or mucous membranes. Inhalation of aerosolised bacteria.	Hunting & Butchering Butchering	
		Yersinia pseudotuberculosis (NB More likely in temperate rather than tropical climates) and *Y.*	(Aschfalk et al., 2008) Norway; (Henderson, 1984) New Zealand; (Fukushima and Gomyoda, 1991) Japan.	F of *C. elaphus*; F of *C. elaphus, D. dama & C. Canadensis*; F of *C. nippon*	Ingestion of raw or undercooked meat or tissues.	Consumption	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		enterocolitica					
Mammalia	Sciuridae	*Francisella tularensis*	(Wobeser et al., 2009) Canada.	S and PM of *Spermophilus richardsonii* & *Spermophilus franklinii*.	Ingestion of raw or undercooked meat or tissues. Direct contact with infected animals via mucous membranes or broken skin. Inhalation of aerosolised bacteria.	Consumption Hunting & Butchering Butchering	(Bow and Brown, 1946) Canada; (Magee et al., 1989) USA.
		Leptospira spp.	(Dirsmith et al., 2013) USA; (Gozzi et al., 2013) Argentina; (Montes et al., 2011) Peru; (Thayaparan et al., 2013) Malaysia.	PM of *Sciurus niger*; PM of introduced *Callosciurus erythraeus*; S of *Sciurus stramineus*; S of *Callosciurus notatus*.	Ingestion of urine contaminated meat. Contact with infected urine via skin & mucous membranes.	Consumption Hunting & Butchering	(Diesch et al., 1967) USA; (Masuzawa et al., 2006) Japan.
		Yersinia pestis	(Cui et al., 2008) China; (Stevenson et al., 2003) & (ProMED-mail, 2013) USA; (Wobeser et al., 2009) Canada.	PM of *Marmota himalayana*; PM of *Cynomis ludovicianus*; PM of *Spermophilus*	Contact with infected secretions or tissues via bites, scratches,	Hunting & Butchering	(Li et al., 2005a) China.

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
				beecheyi; PM of *Spermophilus species,* not reported which ones.	damaged skin or mucous membranes. Inhalation of aerosolised bacteria.	Butchering	
Mammalia	Viverridae	*Bartonella henselae*	(Sato et al., 2013) Japan.	PM of *Paguma larvata.*	Animal bite or scratch transmission.	Hunting	(Miyazaki et al., 2001) Japan.
		Campylobacter spp	(Lee et al., 2011b) Japan.	F from PM of *P. larvata.*	Ingestion of raw or undercooked meat or tissues. Faeco-oral transmission.	Consumption Hunting & Butchering	
		Salmonella spp	(Lee et al., 2011b) Japan.	F from PM of *P. larvata.*	Ingestion of raw or undercooked meat or tissues. Faecal-oral transmission.	Consumption Hunting & Butchering	
		Streptococcus dysgalactiae	(Li et al., 2012) China.	PM of *P. larvata.*	Direct contact with infected animals or carcasses, often via broken skin.	Hunting & Butchering	

WILDLIFE HOST		**ZOONOTIC BACTERIA**					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		Yersinia pseudotuberculosis	(Lee et al., 2011b) Japan.	F from PM of *P. larvata.*	Ingestion of raw or undercooked meat or tissues.	Consumption	
Mammalia	Caprinae	*Brucella spp*	(Ferroglio et al., 1998) Italy; (Garin-Bastuji et al., 1990) France; (Wazed Ali Mollah and McKinney, 2001) UAE.	S of *Capra ibex*; S of *Rupicapra rupicapra*; PM of captive *capra ibex nubiana.*	Ingestion of raw or undercooked meat or tissues. Direct contact with infected body fluids or tissues via broken skin or mucous membranes.	Consumption Hunting & Butchering	
		Campylobacter spp	(Carbonero et al., 2014) Spain	F from *Ovis mussimon.*	Ingestion of raw or undercooked meat. Faeco-oral transmission.	Consumption Hunting & Butchering	
		Chlamydophilia spp	(Cubero-Pablo et al., 2000) & (Salinas et al., 2009) Spain; (Kinjo and Minamoto, 1987) Japan.	S of *O. mussimon & Capra pyrenaica*; S of *O. mussimon*; *C pyrenaica & R. pyrenaica*; S of *Capricornis crispis.*	Aerogenous or cutaneous transmission via infected secretions or excretions.	Hunting & Butchering	
		Escherichia coli Shiga toxin	(Obwegeser et al., 2012) Switzerland.	F for PCR of *C. ibex*	Ingestion of raw or undercooked	Consumption	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		producing			meat or tissues. Faecal-oral transmission.	 Hunting & Butchering	
		Leptospira spp	(Kinjo and Minamoto, 1987) Japan.	S of *C. crispis*.	Ingestion of urine contaminated meat. Contact with infected urine via skin & mucous membranes.	Consumption Hunting & Butchering	
		Mycobacterium bovis	(Pavlik et al., 2002) Czech Republic.	PM of *Capra aegagrus*.	Ingestion of raw or undercooked or meat or tissues. Inhalation of aerosolised bacteria. Direct contact via damaged skin or wounds.	Consumption Hunting & Butchering Hunting & Butchering	
		Salmonella spp	(Billinis, 2013) Europe; (Pioz et al., 2008) France.	PM of *Ammotragus lervia*; S of *R. rupicapra.*	Ingestion of raw or undercooked meat or tissues. Faecal-oral transmission.	Consumption Hunting & Butchering	
Mammalia	Pteropodidae	*Leptospira spp*	(Cox et al., 2005) &	PCR of *Pteropus*	Ingestion of urine	Consumption	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			(Smythe et al., 2002) Australia; (Thayaparan et al., 2013) Malaysia.	*conspicillatus, P. alecto, P. poliocephalus & P. scapulatus*; S of *P. conspicillatus, P. alecto, P. poliocephalus & P. scapulatus*; S of *Cynopterus brachyotis & Penthetor lucasi.*	contaminated meat. Contact with via skin & mucous membranes.	Hunting & Butchering	(Vashi et al., 2010) USA.
		Salmonella spp	(Mühldorfer, 2013) Madagascar.	PM of subfamily *Pteropodinae spp.*	Ingestion of raw or uncooked meat or tissues. Faecal-oral transmission.	Consumption Hunting & Butchering	
		Yersinia pseudotuberculosis	(Childs-Sanford et al., 2009) USA.	PM of captive *Rousettus aegyptiacus.*	Ingestion of raw or undercooked meat.	Consumption	
Mammalia	Hystricidae	*Leptospira spp*	(Bahaman and Ibrahim, 1988), (Kadir et al., 2012) & (Smith et al., 1961) Malaysia.	S of *Atherrurus macrourus*; S of *Hystrix brachyuran*; S of *A. macrourus.*	Ingestion of urine contaminated meat. Contact with infected urine via skin & mucous membranes.	Consumption Hunting & Butchering	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
Mammalia	Ursidae	*Brucella spp*	(Chomel et al., 1998) & (O'Hara et al., 2010) USA; (Tryland et al., 2001a) Norway.	S of *Ursus arctos & Ursus americanus*; S of *Ursus maritimus*; S of *U. maritimus*.	Ingestion of raw or undercooked meat or tissues. Direct contact with infected body fluids or tissues via broken skin or mucous membranes.	Consumption Hunting & Butchering	
		Francisella tularensis	(Chomel et al., 1998) USA; (Hotta et al., 2012) Japan.	S of *U. arctos & U. americanus*; S of *Ursus thibetanus japonicas*.	Ingestion of raw or undercooked meat or tissues. Direct contact with infected animals via mucous membranes or broken skin. Inhalation of aerosolised bacteria.	Consumption Hunting & Butchering Butchering	(Chase et al., 1980) USA.
		Leptospira spp	(Bronson et al., 2014) & (Zarnke, 1983) USA; (Modric and Huber,	S of *U. americanus*; S of *U. arctos*; S of *U. arctos*; S of *U. arctos*.	Ingestion of urine contaminated meat.	Consumption	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			1993) & (Slavica et al., 2010) Croatia.		Contact with infected urine via skin & mucous membranes.	Hunting & Butchering	(Anderson et al., 1978) USA.
		Yersinia pestis	(Clover et al., 1989) & (Ruppanner et al., 1982) USA.	S of *U. americanus* for both.	Contact with infected secretions or tissues via bites, scratches, damaged skin or mucous membranes. Inhalation of aerosolised bacteria.	Hunting & Butchering Hunting & Butchering	
Mammalia	Cercopithecidae	*Campylobacter spp*	(Andrade et al., 2007) Brazil; (Kalashnikova et al., 2002) Russia; (Sestak et al., 2003) USA; (Tribe and Fleming, 1983) UK.	F from captive *Macaca mulatta* for first 2 studies; F from captive *M. mulatta & M. fascicularis*; F from captive *M. fascicularis*.	Ingestion of raw or undercooked or raw meat or tissues. Faeco-oral transmission.	Consumption Hunting & Butchering	
		Leptospira spp	(Thayaparan et al., 2013) Malaysia.	S of captive & free-ranging monkeys including *M.*	Ingestion of urine contaminated meat.	Consumption	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
				nemestrina.	Contact with infected urine via skin & mucous membranes.	Hunting & Butchering	
		Mycobacterium avium	(Goodwin et al., 1988) USA; (Singh et al., 2011) India.	PM of captive *M. mulatta & M. fascicularis*; PM of wild *M. mulatta.*	Ingestion of contaminated meat. Faeco-oral transmission.	Consumption Hunting & Butchering	
		Mycobacterium bovis or M. tuberculosis	(Hasselschwert and Ostrowski, 1999) & (Janssen et al., 1989) USA; (Wilbur et al., 2012) Gibraltar, Indonesia, Nepal, Singapore, Thailand.	PM of captive *M. fascicularis*; PM of *Macaca thibetans*; O of 11 different *Macaca* species (captive and wild)	Ingestion of raw or undercooked meat or tissues. Inhalation of aerosolised bacteria. Direct contact via damaged skin or wounds.	Consumption Hunting & Butchering Hunting & Butchering	(Une and Mori, 2007) Japan.
		Salmonella spp	(Tribe and Fleming, 1983) UK.	F from captive *M. fascicularis.*	Ingestion of raw or undercooked meat or tissues. Faecal-oral transmission.	Consumption Hunting & Butchering	
		Shigella spp (reported in captive	(Lee et al., 2011a) Japan; (Tribe and	F from captive *M. mulatta*; F from	Ingestion of faecal	Consumption	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		monkeys)	Fleming, 1983) UK.	captive *M. fascicularis.*	contaminated meat. Faeco-oral transmission.	Hunting & Butchering	(Kennedy et al., 1993) UK.
Mammalia	Felidae	*Bartonella henselae*	(Chomel et al., 2004), (Rotstein et al., 2000) & (Yamamoto et al., 1998) USA; (Molia et al., 2004) Kenya, South Africa & Tanzania.	S of wild and captive *Puma concolor & Lynx rufus*; S of wild *P. concolor subspecies*; S of 26 wild felid species & subspecies (wild and captive); S of wild *Panthera leo & Acinonyx jubatus*.	Animal bite or scratch transmission.	Hunting	
		Leptospira spp	(Labelle et al., 2000) Canada; (Millán et al., 2009) Spain; (Ullmann et al., 2012) Brazil.	S of *Lynx Canadensis and L. rufus*; S of *Lynx pardinus*; S of *Leopardus pardalis & Leopardus wiedii..*	Ingestion of urine contaminated meat. Contact with infected urine via skin & mucous membranes.	Consumption Hunting & Butchering	
		Pasteurella spp	(Saxena et al., 2006) India; (Woolfrey et al., 1985) USA.	PCR of *Panthera tigris*; O of *P. tigris.*	Animal bite transmission.	Hunting	(Capitini et al., 2002) & (Durazo and Lessenger, 2006) USA;

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
							(Isotalo et al., 2000) Canada.
		Yersinia pestis	(Salkeld and Stapp, 2006) & (ProMED-mail, 2010a) USA.	S of *L. rufus, L. canadensis & Felis cougar*; PM of *Puma concolor*.	Contact with infected secretions or tissues via bites, scratches, damaged skin or mucous membranes. Inhalation of aerosolised bacteria.	Hunting & Butchering Butchering	
Mammalia	Manidae	Not reported					
Mammalia	Elephantidae	*Bacillus anthracis*	(Priya et al., 2009) & (Yasothai and Shamsudeen, 2014) India	PM of *Elephas maximus* for both.	Ingestion of raw or undercooked meat or tissues. Contact with contaminated animal products (e.g. fur, hide, bone) via broken skin. Inhalation of spores (rare).	Consumption Butchering Butchering	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		Mycobacterium spp (*M. tuberculosis* reported in captive elephants)	(Angkawanish et al., 2010) Thailand; (Mikota et al., 2001) USA; (Ong et al., 2013) Malaysia; (Sarma et al., 2006) India; (Obanda et al., 2013) Kenya; (ProMED-mail, 2010b) Nepal.	PM of captive *E. maximus*; PM of captive *E. maximus*; S & PCR of captive *E. maximus*; O & PM of captive *E. maximus*; PM of wild *Loxodonta Africana*; PM of free-ranging and captive *E. maximus*.	Ingestion of raw or undercooked meat or tissues. Inhalation of aerosolised bacteria. Direct contact via damaged skin or wounds.	Consumption Hunting & butchering Hunting & butchering	(Michalak et al., 1998) & (Murphree et al., 2011) USA.
Reptilia	Squamata	*Campylobacter spp (e.g. C. fetus)*	(Gilbert et al., 2014) The Netherlands; (Wang et al., 2013a) Taiwan.	F from a variety of captive lizards and snakes; F from a variety of captive & wild Squamata.	Ingestion of raw or undercooked meat or tissues. Faeco-oral transmission.	Consumption Hunting & Butchering	(Patrick et al., 2013) USA.
		Dermatophilus congolensis	(Montali et al., 1975) & (Wellehan et al., 2004) USA.	O of captive *Pogona barbata*; O of captive *Ophiophagus hannah.*	Direct contact with infected reptile skin.	Hunting & Butchering	
		Edwardsiella tarda	(Ferreira Junior et al., 2009) Brazil; (Koeboelkuti et al., 2013) Romania.	O of wild and captive *Crotalus durissus terrificus*; O of captive *Natrix natrix.*	Ingestion of contaminated meat. Faeco-oral transmission. Transcutaneous transmission via a	Consumption Hunting & Butchering for both	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
					wound.		
		Salmonella spp	(Briones et al., 2004) Spain; (Burnham et al., 1998) USA;(Kuroki et al., 2013) Japan.	F from wild snakes & lizards including *Elaphe scalaris, Malpolon monspessulannus, Tarentola mauritanica Timon lepida*; F from captive *Iguana iguana*; F of 6 different species of snakes.	Ingestion of raw or undercooked meat. Faeco-oral transmission. Animal bite and scratch transmission.	Consumption Hunting & Butchering Hunting	(Bhatt et al., 1989; Corrente et al., 2006; Friedman et al., 1998; Kelly et al., 1995) USA.
Reptilia	Testudines	*Campylobacter spp (e.g. C. fetus)*	(Gilbert et al., 2014) The Netherlands;(Wang et al., 2013b) Taiwan.	F from a variety of captive testudines; F from a variety of captive & wild testudines, including *Trachemys scripta elegans, Emydidae sp.*	Ingestion of raw or undercooked meat. Faeco-oral transmission.	Consumption Hunting & Butchering	(Patrick et al., 2013) & (Tu et al., 2004b) USA.
		Dermatophilus congolensis	(Bemis et al., 1999) USA.	O of captive tortoises *Chersina angulate & Testudo kleinmanni.*	Direct contact with infected reptile skin.	Hunting & Butchering	
		Edwardsiella tarda	(Cai et al., 1997) & (Yan et al., 2013) China; (Ferronato et al.,	PM of *Trionyx sinensis* for both; O of wild *Phrynops*	Ingestion of contaminated meat.	Consumption	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			2009) Brazil; (Otis and Behler, 1973) USA.	*geoffroanus*; F from 8 different captive turtle species.	Faeco-oral transmission. Transcutaneous transmission via a wound.	Hunting & Butchering for both	(Nagel et al., 1982) USA.
		Salmonella spp	(Briones et al., 2004) & (Hidalgo-Vila et al., 2007) Spain.	F from wild tortoises including *Testudo graeca & T. marginata*; F from wild *Testudo graeca, Emys orbicularis & Mauremys leprosa.*	Ingestion of raw or undercooked meat. Faeco-oral transmission. Animal bite and scratch transmission.	Consumption Hunting & Butchering. Hunting	(Fukushima et al., 2008) Japan. (Harris et al., 2009) USA.
Reptilia	Crocodylia	*Dermatophilus congolensis*	(Buenviaje et al., 1998) Australia.	O of captive *Crocodylus porosus.*	Direct contact with infected animal skin.	Hunting & Butchering	
		Edwardsiella tarda	(Charruau et al., 2012) Mexico; (Johnston et al., 2010) USA.	O of *Crocodylus acutus & C. moreletii*; F from *Alligator mississippiensis.*	Ingestion of contaminated meat. Faeco-oral transmission. Transcutaneous transmission via a wound.	Consumption Hunting & Butchering for both.	
		Salmonella spp	(Huchzermeyer, 1991)	F from captive	Ingestion of raw	Consumption	

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	Taxonomic order or family	Bacterial pathogen	Scientific reference and country (when known)	Sampling method and wildlife host	Potential transmission route from wildlife to human	Potential zoonotic risk from hunting, butchering or consumption	Actual zoonotic risk (scientific evidence)
			South Africa; (Manolis et al., 1991) Australia.	*Crocodylus niloticus* PM of captive *Crocodylus johnstoni and C. porosus.*	or undercooked meat (Magnino et al., 2009). Faeco-oral transmission. Animal bite and scratch transmission.	Hunting & Butchering Hunting	
Aves	Galliformes	*Campylobacter spp*	(Díaz-Sánchez et al., 2012) Spain; (Taema et al., 2008) UK; (Tresierra-Ayala et al., 2006) Peru; (Yogasundram et al., 1989) USA.	F from captive & wild *Alectoris rufa*; F from captive *Gallus gallus*; F from wild galliformes; PM of variety of galliformes including *G. gallus, Phasianus colchicus, Pavo cristanus.*	Ingestion of raw or undercooked meat. Faeco-oral transmission.	Consumption Hunting & Butchering	
		Chlamydia psittaci	(Trávniček et al., 2000) Slovakia; (Vanrompay et al., 1993) USA.	S of captive *P. colchicus*; S of a variety of galliformes including *P. colchicus.*	Inhalation of aerosolised bacteria from infected respiratory secretions or dried faeces.	Hunting & Butchering NB A risk for immune-compromised humans	
		Erysipelothrix	(Hennig et al., 2002) &	PM for PCR of	Direct contact	Hunting &	(Mutalib et al.,

WILDLIFE HOST		ZOONOTIC BACTERIA					
Animal class	**Taxonomic order or family**	**Bacterial pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		rhusiopathiae	(Mutalib et al., 1995) USA; (Pettit et al., 1976) Canada.	captive *P. colchicus*; PM of captive *Coturnix japonica*; PM of captive *Alectoris graeca.*	with animal products via damaged skin or wounds.	Butchering	1995) USA.
		Mycobacterium spp (e.g. M.avium, M. genovense)	(Gyimesi et al., 1999) USA; (Keymer et al., 1982) UK; (Portaels et al., 1996) Belgium.	PM of a variety of captive galliformes; PM of a variety of captive galliformes; PM of captive *Coturnix chinensis & Lophortyx californica.*	Inhalation or ingestion of aerosolised bacteria.	Hunting & Butchering NB A risk for immune-compromised humans.	
		Salmonella spp	(Joseph et al., 1988) Malaysia; (Samaha et al., 2012) Egypt.	PM of captive *G. gallus*; S of a variety of wild Galliformes.	Ingestion of raw or undercooked meat. Faeco-oral transmission.	Consumption Hunting & Butchering	
		Yersinia enterocolitica	(Kato et al., 1985) Japan; (Shayegani et al., 1986) USA.	PM of wild *P. colchicus tohkaidi & Bumbusicola thoracica thoracica*; PM of wild *Meleagris gallopavo & Bonasa umbellus.*	Ingestion of raw or undercooked meat.	Consumption	

Table A3: Potential zoonotic parasitic pathogens from wildlife sold in the wild meat trade

Legend: F= faecal sampling, PCR= PCR testing, PM= post mortem examination, S= serology, O= other.

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
Mammalia	Suidae	*Balantidium coli*	(Nakauchi, 1999) Japan; (Solaymani-Mohammadi et al., 2004) Iran.	F from *Sus scrofa*; PM of *S. scrofa.*	Ingestion of faecal contaminated meat. Faeco-oral transmission of cysts (e.g. contamination of fomites or hands).	Consumption Hunting & Butchering	
		Cryptosporidium spp	(Atwill et al., 1997) USA; (Castro-Hermida et al., 2011) Spain; (Němejc et al., 2012) Czech Republic.	F from *S. scrofa*; F from *S. scrofa*; PCR of F from *S. scrofa*.	Ingestion of faecal contaminated meat. Faeco-oral transmission of oocysts (e.g. contamination of fomites or hands).	Consumption Hunting & Butchering	

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		Giardia spp	(Atwill et al., 1997) USA; (Castro-Hermida et al., 2011) Spain.	F from *S. scrofa*; F from *S. scrofa*.	Ingestion of faecal contaminated meat. Faeco-oral transmission of cysts (e.g. contamination of fomites or hands).	Consumption Hunting & Butchering	
		Spirometra spp	(Bengtson and Rogers, 2001) USA; (Lee et al., 2013) Korea; (Pavlov, 1988) Australia.	PM of *S. scrofa* for all.	Ingestion of plerocercoid larva from raw or undercooked meat.	Consumption	(Tanaka et al., 1997) Japan.
		Taenia spp	(Fan, 1988) Taiwan; (Ito et al., 2003) Asian countries; (Solaymani-Mohammadi et al., 2003) Iran	PM of *S. scrofa* for all.	Ingestion of infective larvae from raw or undercooked meat & viscera.	Consumption	(Fan, 1988) & (Fan et al., 1992) Taiwan.
		Toxoplasma gondii	(Bártová et al., 2006) Czech	S from PM of *S. scrofa* for all.	Ingestion of tissue cysts from raw or	Consumption	(Choi et al., 1997) South Korea.

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			Republic; (Gauss et al., 2005) Spain; (Gresham et al., 2002) USA; (Kang et al., 2013) South Korea; (Puvanesuaran et al., 2013) Malaysia.		undercooked meat & viscera. Faeco-oral transmission from carcass preparation.	Butchering	
		Trichinella spp	(García-Sánchez et al., 2009) Spain; (Gresham et al., 2002) USA; (Kang et al., 2013) South Korea; (Nöckler et al., 2006) Germany; (Pozio et al., 1999) Papua New Guinea.	PM of *S.* scrofa; S from PM of *S. scrofa*; S from PM of *S. scrofa*; PM of *S. scrofa*; S from *S. scrofa*.	Ingestion of tissue cysts from raw or undercooked meat & viscera.	Consumption	(Cui et al., 2011) China; (De Bruyne et al., 2006) & (Ranque et al., 2000) France; (García et al., 2005) Chile; (Gołab and Sadkowska-Todys, 2005) Poland; (Greenbloom et al., 1996) Canada; (Jongwutiwes et al., 1998) & (Kusolsuk et al., 2010) Thailand; (Owen et al., 2005) Papua New Guinea; (Rodríguez et al., 2004)

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
							Spain.
		Trichuris spp	(Gipson et al., 1999) USA; (Järvis et al., 2007) Estonia; (Solaymani-Mohammadi et al., 2003) Iran.	PM of *S. scrofa* for all.	Ingestion of faecal contaminated meat. Faeco-oral transmission of embryonated eggs (e.g. contamination of hands or equipment).	Consumption Hunting & Butchering	
Mammalia	Cervidae	*Cryptosporidium spp*	(Castro-Hermida et al., 2011) Spain; (Perz and Le Blancq, 2001) & (Rickard et al., 1999) USA.	F from *Capreolus capreolus*; F from *Odocoileus virginianus* for both.	Ingestion of faecal contaminated meat. Faeco-oral transmission of oocysts.	Consumption Hunting & Butchering	
		Giardia spp	(Castro-Hermida et al., 2011) Spain.	F from *C. capreolus*.	Ingestion of faecal contaminated meat. Faeco-oral	Consumption Hunting &	

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
					transmission of cysts.	Butchering	
		Sarcocystis spp	(Duncan et al., 2000) USA; (Hernández-Rodríguez et al., 1992) & (López et al., 2003) Spain; (Vinhas, 2014) Portugal.	PM of *O. virginianus*; PM of *Dama dama*; PM of *C. capreolus*; PM of *Cervus elaphus & D. dama.*	Ingestion of tissue cysts from raw or undercooked meat (Lee et al., 2014).	Consumption	
		Toxoplasma gondii	(Dubey et al., 2008) USA; (Gaffuri et al., 2006) Italy; (Gamarra et al., 2008) Spain; (Vikøren et al., 2004) Norway.	PM of *O. virginianus*; S of *C. capreolus*; S of *C. capreolus*; S of *C. capreolus, C. elaphus, Alces alces & R. tarandus.*	Ingestion of tissue cysts from raw or undercooked meat & viscera. Faeco-oral transmission from carcass preparation.	Consumption Butchering	(McDonald et al., 1990) Canada; (Ross et al., 2001) & (Sacks et al., 1983) USA.
		Trichinella spp	(Bessonov, 1981) Russia.	PM of *R. tarandus.*	Ingestion of tissue cysts from raw or undercooked meat & viscera.	Consumption	(Ramasoota, 1991) Thailand.

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
Mammalia	Sciuridae	*Sarcocystis spp*	(Latif et al., 2010) Malaysia; (Lindsay et al., 2000) USA.	PM of *Sciurus carolinensis & Xerus* inauris; PM of *Spermophilus tridecemlineatus*.	Ingestion of tissue cysts from raw or undercooked meat (Fazly et al., 2013).	Consumption	
		Toxoplasma gondii	(Carrasco et al., 2006) Spain; (Dubey et al., 2006) USA; (Jittapalapong et al., 2011) Thailand; (Jokelainen and Nylund, 2012) Finland.	PM of imported *Sciurus vulgaris*; PM of *S. carolinensis*; S of *Callosciurus sp.* & *Menetes berdmorei;* PM of *S. vulgaris*.	Ingestion of tissue cysts from raw or undercooked meat (Fazly et al., 2013). Faeco-oral transmission from carcass preparation.	Consumption Butchering	(Alvarado-Esquivel et al., 2008) Mexico.
Mammalia	Viverridae	*Gnathostoma spp*	(Colon and Patton, 2013) Malaysia.	F from *Viverra tangalunga.*	Ingestion of parasite from raw or undercooked meat & tissues.	Consumption	
		Sarcocystis spp	(Fazly et al., 2013) Malaysia.	PM of unspecified civet species.	Ingestion of tissue cysts from raw or undercooked meat (Fazly et al., 2013).	Consumption (Fazly et al., 2013)	

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		Toxoplasma gondii	(Oronan et al., 2013) The Philippines.	S of *V. tangalunga* & *Paradoxurus hermaphrodites.*	Ingestion of tissue cysts from raw or undercooked meat. Faeco-oral transmission from carcass preparation.	Consumption Butchering	
Mammalia	Caprinae	*Toxoplasma gondii*	(Kinjo and Minamoto, 1987) & (Sakae and Ishida, 2012) Japan.	S of *Capricornis crispis*; S from PM of *C. crispis*	Ingestion of tissue cysts from raw or undercooked meat. Faeco-oral transmission from carcass preparation.	Consumption Butchering	
Mammalia	Pteropodidae	Not reported					
Mammalia	Hystricidae	Not reported					
Mammalia	Ursidae	*Sarcocystis spp*	(Latif et al., 2010) Malaysia.	PM of *Helarctos malayanus.*	Ingestion of tissue cysts from raw or undercooked meat.	Consumption	
		Toxoplasma gondii	(Bronson et al.,	S of *Ursus*	Ingestion of tissue	Consumption	

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			2014), (Chomel et al., 1995) & (Dubey et al., 2013) USA; (Oksanen et al., 2009) Greenland.	*americanus*; S of *U. americanus*; S of *Ursus arctos & U. americanus*; S of *Ursus maritimus*	cysts from raw or undercooked meat. Faeco-oral transmission from carcass preparation.	Butchering	
		Trichinella spp	(Åsbakk et al., 2010) Norway; (Born and Henriksen, 1990) Greenland; (Chomel et al., 1998) USA; (Wang et al., 2007) China.	S of *U. maritimus*; PM of *U. maritimus*; S of *U. arctos & U. americanus*; S of unspecified bears.	Ingestion of tissue cysts from raw or undercooked meat.	Consumption	(Ancelle et al., 2005) & (Schellenberg et al., 2003) Canada; (Hall et al., 2012) & (Hill et al., 2005) USA; (Khamboonruang, 1991) Thailand; (Yamaguchi, 1991) Japan.
Mammalia	Cercopithecidae	*Ancylostoma spp*	(Hussain et al., 2013) India; (Lane et al., 2011) Indonesia; (Lim et al., 2008) Malaysia; (Pourrut et al., 2011) Cameroon.	F from wild *Macaca silenus*; F from *M. fascicularis*; F from captive *M. arctoides, M. radiata & M. nemestrina*; F from 14 different Cercopithecidae	Transcutaneous transmission: penetration of infective larvae through the skin.	Butchering	

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
				species (wild & pets).			
		Balantidium coli	(Jha et al., 2011) Nepal; (Lim et al., 2008) Malaysia.	F from *M. mulatta*; F from captive *M. arctoides*,*M. radiata*, *M. nemestrina & M. fascicularis*.	Ingestion of faecal contaminated meat. Faeco-oral transmission of cysts.	Consumption Hunting & Butchering	
		Cryptosporidium spp	(Ekanayake et al., 2007) Sri Lanka; (Karim et al., 2014) China; (Lane et al., 2011) Indonesia; (Lim et al., 2008) Malaysia.	F from wild *M. sinica sinica*; F for PCR from wild & captive *M. mulatta & M. fascicularis*; F from wild *M. fascicularis*; F from captive *M. arctoides, M. radiata & M. nemestrina.*	Ingestion of faecal contaminated meat. Faeco-oral transmission of oocysts.	Consumption Hunting & Butchering	
		Entamoeba histolytica	(Huffman et al., 2013) Sri Lanka; (Jha et al., 2011) Nepal; (Takano et al., 2005) Japan.	F from wild *M. sinica sinica*; F from *M. mulatta*; F from captive *M. fascicularis*.	Ingestion of faecal contaminated meat. Faeco-oral transmission of	Consumption Hunting & Butchering	

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
					cysts (e.g. contamination of fomites or hands).		
		Giardia spp	(Karim et al., 2014) China; (Lane et al., 2011) Indonesia.	F for PCR from captive & wild *M. assamensis*, *M. fuscata*, *M. mulatta* & *M. fascicularis*; F from wild *M. fascicularis*.	Ingestion of faecal contaminated meat. Faeco-oral transmission of cysts.	Consumption Hunting & Butchering	
		Oesophagostomum spp	(Arizono et al., 2012) Japan; (Gotoh et al., 2001) Indonesia.	F from wild *M. fuscata*; F from wild *M. hecki & M. hecki hybrids*.	Ingestion of faecal contaminated meat. Faeco-oral transmission of filariform larvae (e.g. contamination of hands or equipment).	Consumption Hunting & Butchering	
		Sarcocystis spp	(Tappe et al., 2013) Malaysia; (Tian et al., 2012) & (Yang	PM of wild *M. fascicularis*, PM of *M. fascicularis*; PM of	Ingestion of tissue cysts from raw or undercooked	Consumption	

WILDLIFE HOST		ZOONOTIC PARASITES					
Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			et al., 2005) China.	captive *M. fascicularis*.	meat.		
		Strongyloides spp	(Dewit et al., 1991) Sri Lanka; (Gotoh et al., 2001) Indonesia; (Hussain et al., 2013) & (Sharma et al., 2013) India; (Jha et al., 2011) Nepal; (Pourrut et al., 2011) Cameroon; (Wenz-Muecke et al., 2013) Thailand.	F from wild *M. sinica*; F from wild *M. hecki & M. hecki hybrids*; F from wild *M. silenus*; F from wild *M. mulatta*; F from *M. mulatta*; F from 14 different Cercopithecidae species (wild & pets); F from wild *M. fascicularis*.	Direct penetration of infective larvae through the skin (transcutaneous transmission) or oral mucosa (faeco-oral transmission).	Hunting & Butchering	
		Toxoplasma gondii	(Ekanayake et al., 2004) Sri Lanka.	S of *M. sinica*	Ingestion of tissue cysts from raw or undercooked meat (Fazly et al., 2013). Faeco-oral transmission from carcass preparation.	Consumption Butchering	
		Trichuris spp	(Arizono et al.,	F from wild *M.*	Ingestion of	Consumption	

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			2012) Japan; (Dewit et al., 1991) & (Huffman et al., 2013) Sri Lanka; (Gotoh et al., 2001) Indonesia; (Jha et al., 2011) Nepal; (Lim et al., 2008) Malaysia; (Pourrut et al., 2011) Cameroon; (Sharma et al., 2013) India; (Wenz-Muecke et al., 2013) Thailand.	*fuscata*; F from wild *M. sinica* for both surveys in Sri Lanka; F from wild *M. hecki & M. hecki hybrids*; F from *M. mulatta*; F from 14 different Cercopithecidae species (wild & pets); F from a variety of captive Cercopithecidae species; F from wild *M. mulatta;* F from wild *M. fascicularis*.	contaminated meat. Faeco-oral transmission (e.g. contamination of hands or equipment).	Hunting & Butchering	
Mammalia	Felidae	*Cryptosporidium spp*	(Lim et al., 2008) Malaysia.	F from captive *Panthera tigris sumatrae, P.tigris. corbetti & P.tigris jacksoni.*	Ingestion of faecal contaminated meat. Faeco-oral transmission of oocysts (e.g. contamination of fomites or hands).	Consumption Hunting & Butchering	

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Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
		Toxoplasma gondii	(Demar et al., 2008) French Guiana; (Goodrich et al., 2012) Russia; (Paul-Murphy et al., 1994) USA; (Thiangtum et al., 2006) Thailand.	PCR of *Panthera onca*; S of *P. tigris altaica*; S of *Puma concolor*; S of captive *P. tigris*, *Panthera pardua & Neofelis nebulosa.*	Ingestion of faecal contaminated meat. Faeco-oral transmission through the ingestion of oocysts (e.g. contamination of fomites or hands).	Consumption Hunting & Butchering	(Carme et al., 2009) French Guiana.
		Trichinella spp	(Blaga et al., 2009) Romania; (Ribicich et al., 2010) Argentina.	PM of wild *Felis silvestris & Lynx lynx*; PM of wild *P. concolor*.	Ingestion of tissue cysts from raw or undercooked meat.	Consumption	
Mammalia	Manidae	Not reported					
Mammalia	Elephantidae	*Cryptosporidium parvum*	(Fayer, 2004) review; (Samra et al., 2011) South Africa.	F from *Elaphus maximus & Loxodonta africana*; F from *L. africana*	Ingestion of faecal contaminated meat. Faeco-oral transmission of oocysts.	Consumption Hunting & Butchering	

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Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
Reptilia	Squamata	*Gnathostoma genus (nematode)*	In snakes: (Cho et al., 2007) China; (SOHN and LEE, 1998) Korea.	PM of *Dinodon rufozonatum rufozonatum*; PM of *Agkistrodon brevicaudus*.	Ingestion of larvae from raw or undercooked snake meat.	Consumption	(Akahane et al., 1998) Japan & Thailand; (Seguchi et al., 1995) Japan.
		Pentastomidia (crustacean)	In snakes: (Ayinmode et al., 2010) Nigeria; (Kelehear et al., 2014; Riley and Self, 1981) SE Asia and Australia; (Witchaya Tongtako 2013) Malaysia.	*Pythonidae family*; PM of 7 different snake species; PM of *Python regius*; PM of *Python curtus*.	Ingestion of larvae from raw or undercooked meat. Direct contact with infected reptile respiratory secretions and tissues. Faeco-oral transmission of eggs (e.g. contaminated reptile carcasses, hands).	Consumption Hunting & Butchering Butchering	(Latif et al., 2011) & (Prathap et al., 1969) Malaysia; (Yao et al., 2008) & (Ye et al., 2013) China; (Yapo Ette et al., 2003) Ivory Coast.
		Sarcocystis spp	In snakes: (Daszak and Cunningham, 1995) UK; (Lau et al., 2013) Malaysia;	PM of *Pituophis melanoleucus sayi*; F from *Naja kaouthia*, *Braghammerus*	Ingestion of contaminated meat. Faeco-oral	Consumption Hunting &	(Lau et al., 2014) & (Tappe et al., 2013) Malaysia.

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Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			(More et al., 2014) Germany. In lizards: (Bannert, 1992) Spain.	*reticulatus, Ovophis convictus & Ptyas cainata*; F from *Morelia viridis*); O of *Gallotia simonyi*.	transmission through the ingestion of oocysts from this definitive host.	Butchering	
		Spirometra spp (cestode)	(Cho et al., 1982) South Korea; (Sato et al., 2000) Japan.	PM of a variety of snake species; PM of *Elephe quadrivirgata & Rhabdophis tigrinus tigrinus*.	Ingestion of plerocercoid larva from raw or undercooked meat.	Consumption	(Anantaphruti et al., 2011) & (Wiwanitkit, 2005) Thailand; (Min, 1990) & (Park et al., 2001) South Korea.
		Trichinella spp	(Pozio et al., 2007) Zimbabwe.	PM of *Varanus varius*.	Ingestion of tissue cysts from raw or undercooked meat.	Consumption	(Khamboonruang, 1991) Thailand.
Reptilia	Testudines	*Pentastomidia (crustacean)*	(Curran et al., 2014) USA.	PM of softshell turtles *Apalone species*.	Ingestion of larvae from undercooked or raw meat. Direct contact with infected reptile respiratory secretions and tissues. Faeco-oral	Consumption Hunting & Butchering Butchering	

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					transmission of eggs.		
Reptilia	Crocodylia	*Anisakidae (nematode) e.g. genus Contracaecum*	(Goldberg et al., 1991) Paraguay; (Moravec, 2001) Mexico.	PM of *Caiman* yacare; PM of *Crocodylus moreletii*.	Ingestion of larvae from raw or undercooked meat.	Consumption	
		Pentastomidia	(Junker et al., 1999) South Africa; (Riley and Huchzermeyer, 1995) Republic of Congo.	PM of *Crocodylus niloticus*; PM of *Osteolaemus tetraspis*.	Ingestion of larvae from undercooked or raw meat. Direct contact with infected reptile respiratory secretions and tissues. Faeco-oral transmission of eggs.	Consumption Hunting & Butchering Butchering	
		Trichinella spp	(Foggin et al., 1997) Zimbabwe; (La Grange et al., 2013) South Africa; (Pozio et al., 2007) Mozambique;	PM of *C. niloticus* for first 3 studies; PM of *Crocodylus porosus*.	Ingestion of tissue cysts from undercooked or raw meat.	Consumption	

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Animal class	**Taxonomic order or family**	**Parasitic pathogen**	**Scientific reference and country (when known)**	**Sampling method and wildlife host**	**Potential transmission route from wildlife to human**	**Potential zoonotic risk from hunting, butchering or consumption**	**Actual zoonotic risk (scientific evidence)**
			(Pozio et al., 2004) Papua New Guinea,				
Aves	Galliformes	*Cryptosporidium spp*	(Ng et al., 2006) Australia; (Pagès-Manté et al., 2007) Spain; (Randall, 1986) UK; (Rohela et al., 2005) Malaysia.	F from captive *Gallus gallus, Rolulus roul roul & Tetrastes bonasia rupestris*; PM of captive *Alectoris rufa;* PM of captive *Gallus sonneratii*; F from captive *Argusianus argus*.	Ingestion of faecal contaminated meat. Faeco-oral transmission of oocysts.	Consumption Hunting & Butchering	
		Sarcocystis spp	(Latif et al., 2010) Malaysia.	PM of captive *Numida meleagris*.	Ingestion of tissue cysts from raw or undercooked meat.	Consumption	

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