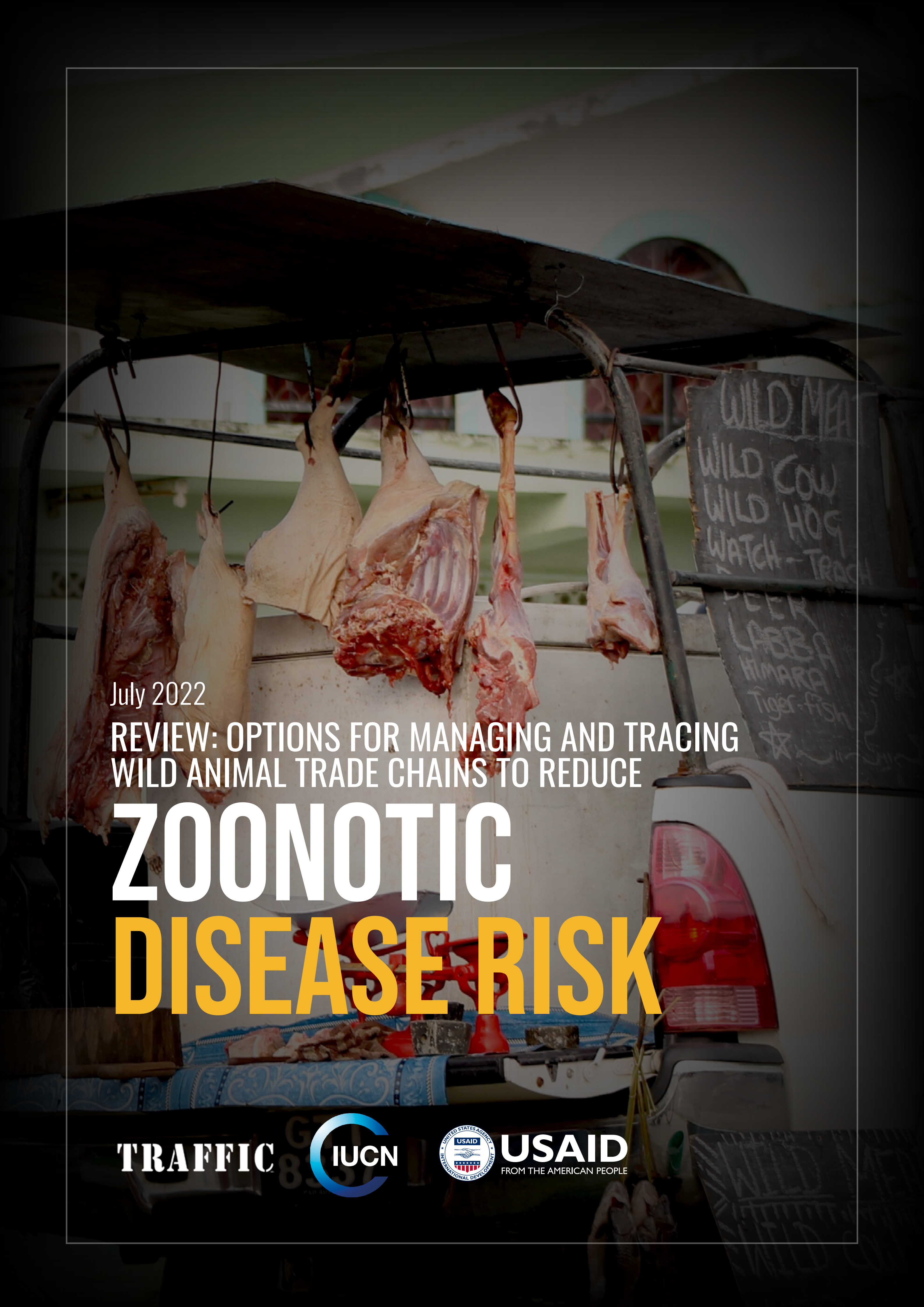

July 2022

REVIEW: OPTIONS FOR MANAGING AND TRACING WILD ANIMAL TRADE CHAINS TO REDUCE ZOONOTIC DISEASE RISK

TRAFFIC
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FROM THE AMERICAN PEOPLE

TRAFFIC REPORT

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TRAFFIC is a leading non-governmental organisation working globally on trade in wild animals and plants in the context of both biodiversity conservation and sustainable development.

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The United States Agency for International Development (USAID) works to end extreme poverty and promote resilient, democratic societies while advancing security and prosperity for America and the world. USAID partnerships and investments save lives, reduce poverty, strengthen democratic governance, and help people emerge from humanitarian crises and progress beyond assistance.

PROJECT LEADER
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Game meat on sale in Dodoma Tanzania

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CONTENTS

ABBREVIATIONS

AEMIS	Australian Export Meat Inspection System
AI	Avian Influenza
APC	Aerobic Plate Count
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species
CCP	Critical Control Point
CPTPP	Comprehensive and Progressive Agreement for Trans-Pacific Partnership
CPW	Collaborative Partnership on Sustainable Wildlife Management
CSIRO	Australia's Commonwealth Scientific and Industrial Research Organisation
CTE	Critical Tracking Events
DAFF	South Africa's Department of Agriculture, Forestry and Fisheries
DALRRD	South Africa's Department of Agriculture, Land Reform and Rural Development
EC	European Commission
EID	Emerging Infectious Disease
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FSC	Forest Stewardship Council
HACCP	Hazard Analysis and Critical Control Points
HPAI	Highly Pathogenic Avian Influenza
IGO	Intergovernmental Organisation
ILRI	International Livestock Research Institute
IUCN	International Union for Conservation of Nature
IWT	Illegal Wildlife Trade
KDE	Key Data Elements
LPAI	Low Pathogenicity Avian Influenza
MEDC	Meat Export Data Collection system
MSC	Marine Stewardship Council
NGO	Non-Governmental Organisation
OIE	World Organisation for Animal Health (name now changed to WOAH)
OPV	On-Plant Veterinarian
QR CODE	Quick Response code
RFID	Radio-Frequency Identification
SBC	Social and Behaviour Change
SRA	State Represented Authority or State Regulatory Authority
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
VPN	Veterinary Procedural Notice
WOAH	World Organisation for Animal Health (formerly OIE)
WHO	World Health Organization
WWF	World Wide Fund for Nature

NOMENCLATURE

For this Review, the terms used are taken to have the following definitions[i, ii]:

TERM	MEANING
Control measure	Any action and activity that can be used to prevent or eliminate a food safety hazard or reduce it to an acceptable level.
Critical Control Point (CCP)	A step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level.
Domesticated species	Species bred in captivity and modified from their wild ancestors to make them more 'useful' to humans, who control their reproduction (breeding), care (shelter, protection against predators) and food supply.
Farmed, captive-bred, or cultivated	In wild animal and plant trade, such terms designate management and production modes distinct from 'wild-sourcing,' with breeding and raising taking place in controlled conditions.
Hazard	An agent (physical, chemical, or biological) with the potential to cause adverse health effects.
Hazard Analysis and Critical Control Points (HACCP)	A system that identifies, evaluates, and controls hazards significant for food safety.
Illegal wildlife trade	Wildlife commerce in contravention of a relevant legal provision. These could include legislation or regulations related to one or more policy concerns: e.g., resource ownership or access rights; nature conservation; human or animal health protection; animal welfare; taxation or other fiscal provisions.
Monitor	The act of conducting a planned sequence of observations or measurements of control parameters to assess whether a CCP is under control.

One Health[iii] One Health is an integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals and ecosystems.

It recognises that the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent.

The approach mobilises multiple sectors, disciplines and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for clean water, energy and air, safe and nutritious food, taking action on climate change, and contributing to sustainable development.

TERM	MEANING
Risk	The estimated probability and severity of adverse health effects following the exposure to a hazard.
Supply chain	The entire stream from harvest (farming in some cases) to processing of a wildlife or other product until it reaches the ultimate consumer.
Traceability	The capacity to find information about where, how, and under what regulatory conditions a product was made.
Wet market	A marketplace selling fresh meat, fish, produce, or other perishable goods (including vegetables) as distinct from 'dry markets' that sell durable goods such as fabrics and electronics.

Wild meat	Meat from wild animals (see 'Wildlife' below). In some countries, the term bushmeat is used to indicate illegally acquired wild (or wildlife-) meat, whereas wild meat can also be game meat from licensed butcheries. This Review focuses on meat from terrestrial wild animals, especially mammals and birds.
Wild species	Non-domesticated wildlife species.
Wild sourced	Wild animals, plants, fungi, or products collected or harvested from free-living (non-captive) populations.
Wildlife	In line with the IUCN definition: 'Living things that are neither human nor domesticated.'
Wildlife market	A venue (physical or online) where wildlife trade is active.
Wildlife pet / Exotic pet	A companion animal living with people that is generally thought of as a wild species rather than a domesticated one.
Wildlife trade	The local or domestic and international commerce in wildlife, inclusive of parts and products derived from them.
Zoonotic disease / Zoonosis[iv]	As defined by the World Health Organization (WHO): A zoonosis is any disease or infection that is naturally transmissible from vertebrate animals or an animal reservoir to humans, either directly, or indirectly through a vector or food-borne. 'Zoonotic disease' describes a disease that first originated in non-human animals, even when the disease is no longer transmitted from animals but continues to circulate within human populations.

[i] https://www.fao.org/3/y1579e/y1579e03.htm
[ii] https://www.traffic.org/site/assets/files/12893/wildlife-trade-and-zoonotic-disease-lexicon.pdf
[iii] https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health
[vi] https://portals.iucn.org/library/node/49880

Bushmeat Market

RECOMMENDATIONS

Based on this review, these priority recommendations have emerged for those working to improve wild animal supply chain management and traceability across various geographical contexts. TRAFFIC welcomes opportunities for collaboration with cross-sectoral partners in any of these steps:

IMPROVE COMMUNICATION AND COLLABORATION

Governments improve communication and collaboration among agencies working on public health, animal health, environmental health, wildlife trade management and collaborating institutions such as Customs and law enforcement agencies. Establishing One Health working groups can help to formalise this cooperation in countries where they are not already established.

IDENTIFY AND ADDRESS RISKS

Government authorities, IGOs, NGOs, donor agencies, and experts working in public health, animal health (inclusive of wildlife health), food safety, natural resource management, law enforcement and Customs collaborate to:

- Establish minimum biosecurity standards for legal wild animal trade;
- Identify and regulate different levels of risks, i.e., which forms of wild animal trade and consumption are unsafe, which ones need special conditions, and which ones are safe in their current state;
- Test supply chain management and traceability approaches across different wild animal trade systems, with adaptation to context-specific risks for safety and sustainability. These groups work closely with wild animal trade stakeholders to implement more transparent practices and regularly monitor and strengthen these practices through feedback loops, while sharing lessons learned via publicly accessible guidance materials.

MAP SUPPLY CHAINS

Wild animal trade stakeholders map their respective supply chains to understand and mitigate risks to safety, sustainability, and legality. This mapping could be either voluntary or required by government regulators.

DEVELOP AND DISSEMINATE DIGITAL TOOLS

Technology companies develop simple, low-cost digital tools for improved supply chain management and traceability, and train developing country government partners in the use and dissemination of these tools to wild animal trade stakeholders.

SUPPORT SAFER BEHAVIOURS

Experts in social and behaviour change (SBC) work with government authorities and wild animal trade stakeholders to assess the role of risky behaviours along these trade chains and formulate SBC approaches to support the sustained adoption of safer behaviours.

INCREASE SUPPLY CHAIN TRANSPARENCY

The exotic pet industry, zoo associations, and members of the scientific research community involved in live wild animal trade pilot approaches to increase the transparency of their respective wild animal supply chains and share best practices with relevant IGOs (e.g., the Quadripartite of WOAH, WHO, FAO, and UNEP, as well as the Secretariats of CITES and CBD) for dissemination to national governments.

SHARE GLOBAL EXPERIENCE

Governments with established regulations for wild animal trade management, including measures to reduce disease transmission risk, proactively share these frameworks and experiences with the global community. This will support ongoing work by CITES[vi] Parties to minimise the risk of future zoonotic disease emergence associated with international wildlife trade.

SHARE AGENCY RESOURCES

Government agencies involved in food safety regulation to share knowledge and resources with agencies working on wild animal trade management.

APPLY GUIDELINES

National focal points for WOAH, working with inter-agency partners across the One Health spectrum, to begin applying the Draft Guidelines for Reducing the Risk of Disease Spillover Events at Markets Selling Wildlife. At the time of publication, these Guidelines were being prepared by a WOAH Ad Hoc Group expert consultation process and are expected to be made public in 2022.

INTEGRATE COSTS

Businesses and associations with expertise in animal supply chain management and traceability to explore the costs of adapting such systems to priority wild animal trade chains, emphasising a systems-based approach and attention to the needs of less regulated contexts. These experts could develop strategies in partnership with wild animal trade stakeholders to integrate these costs along a particular trade chain to minimise any adverse effects on stakeholder livelihoods.

SUPPORT MEASURES FINANCIALLY

Donor agencies and private sector partners financially support small-scale trade chain actors in adopting traceability measures.

[vi] https://cites.org/sites/default/files/eng/com/sc/74/E-SC74-16.pdf

EXECUTIVE SUMMARY

The COVID-19 pandemic and the SARS-CoV-2 virus's suspected wild animal origins[1], [2], [3] have spurred fresh consideration of how to reduce zoonotic disease risks associated with wild animal trade. This Review assesses existing systems for managing and tracing wild animal trade chains to determine best practices for interventions that are context-specific to increase participation and effectiveness. The guiding principle for these management interventions is that where wild animal trade takes place, it should be closely monitored to ensure legality and improve sustainability and safety[4].

Wild meat sold and cooked at a restaurant, Tanzania

This Review is supported by in-depth assessments of three established wild animal trade systems where some degree of disease risk management is already in place:

- Australia's kangaroo meat industry
- South Africa's ostrich meat industry
- France's venison trade

Lessons from these systems and a range of supply chain management and traceability tools from other trades are examined for potential adaptation to other wild animal trade contexts. The focus in assessing each of these examples has concentrated on reducing health risks. However, parallel risks to sustainability and legality also have the potential to be reduced through a more integrated approach to improved supply chain management and traceability. A key assumption for this review is that the more transparent and better managed a trade system is, the easier it would be to identify and monitor potential risks and weed out any illegal, unsustainable or unsafe practices.

When considering the variety of global wild animal trade systems beyond this Review's case studies, there is a broad need for more coherent regulation and monitoring. Trade in domestic livestock has comparatively well-developed biosecurity measures for disease risk reduction, and these measures can be adapted to wild animal trade to build on existing knowledge, regulations, and infrastructure.

The potential for zoonotic disease emergence in wild animal trade can be more complex than in domestic livestock trade due to the diversity of species in trade. Several principles emerge to help prioritise and reduce these risks[5]:

- The risk of zoonotic spillover to humans tends to be higher via wild mammal and wild bird taxa;
- Trade in live animals presents the highest risks compared to other wild animal products, followed by raw meat;
- Disease risks may be amplified along lengthy trade chains with more intermediaries;
- Risks are higher where different species come into contact with each other (including contact with domestic animals and humans).

In implementing traceability for legal wild animal trade chains, technological tools like Apps may help gather and share data, but more important is to map the supply chain and implement consistent monitoring and data gathering at crucial risk points, regardless of the tool used.

While a complete list of recommendations can be found in the Recommendations chapter of this Review, a selection is presented here:

- Governments improve communication and collaboration among agencies working on public health, animal health, environmental health, wildlife trade management and their implementing partners such as Customs and law enforcement;
- Government agencies involved in food safety regulation share knowledge and resources with agencies working on wild animal trade management;
- Government authorities, donor agencies, and experts working in public health, animal health, food safety, natural resource management, law enforcement, and Customs collaborate to test supply chain management and traceability approaches across different wild animal trade systems, and to establish minimum biosecurity standards for legal wild animal trade;
- Wild animal trade stakeholders map their respective supply chains to understand and mitigate risks to safety, sustainability, and legality;
- Businesses and associations with expertise in animal supply chain management and traceability explore the costs of adapting such systems to priority wild animal trade systems, particularly in less regulated contexts.
- Donor agencies and private sector partners financially support small-scale trade chain actors in adopting traceability measures.

INTRODUCTION

COVID-19 has pushed governments, businesses, civil society organisations, and individuals to rethink the risks and probability of pandemics. In considering what measures are needed to prevent future diseases with pandemic potential, a critical approach is to manage human-animal interactions such as wild animal trade that may enable spillover of zoonotic diseases.

Wildlife trade includes domestic and international commerce in a wide range of terrestrial, marine, and freshwater wild species of fauna, flora, and fungi. This Review focuses on trade in wild animals and parts and products derived from these animals, particularly terrestrial wild mammals and birds, based on the relatively higher risk of zoonotic disease transmission from these taxonomic groups[6 7]. Globally, the diversity of species, trade systems, and national legal contexts involved in wild animal trade requires interventions that are both focused and adaptive. Supply chain management and traceability are assessed as tools for improving transparency and reducing disease risks across different trade systems and contexts.

Traceability enables better understanding of a supply chain by monitoring critical points in the chain to gather data on where, how, and under what regulatory conditions a product was made. A traceability system may focus on a particular aspect of production, such as the legality or sustainability of product sourcing, fair treatment of the supply chain's workers, production quality (e.g., organic, halal, etc.), and monitoring for health risks, as is the focus of this Review.

Monitoring for health risks commonly focuses on food safety concerns like contamination and spoilage[8], but in domestic and wild animal supply chains, the need to also monitor for emerging zoonotic diseases is increasingly apparent. There is a growing need to ensure the trade in wild animals carries minimal risk of emerging infectious diseases (EIDs), is ecologically sustainable, and is legal[9]. Traceability, therefore, can be used to monitor and reduce risks of zoonotic disease emergence within wild animal supply chains.

At the most basic level, traceability gathers data to answer "where" and "when" critical events in the supply chain occur.

- **Tracing** moves from the end-consumer backwards along the supply chain to the producer and, where relevant, the producer's suppliers to mitigate risks before they become problematic.
- **Tracking**, in contrast, moves forward along the supply chain from source to consumer and can be used to find and recall risky products after a problem is discovered.

A traceability system captures the type and volume of products traded and the actors involved in any transactions. When the volume of goods changes, this can serve as a red flag that unauthorised products may have been mixed with the authorised products. A red flag enables an investigation at the point where it's raised or at any previous points[10]. Information in a traceability system may allow full access to all users or be limited to authorities to monitor, comply, and preserve confidential business information.

Traceability is sometimes conflated with certification. A certification scheme can document and market a supply chain's adherence to a social or environmental standard, which often relies on being able to trace the supply chain. However, certification is an additional step on top of traceability, and is therefore not a required step in tracing a supply chain. Certification can incur a high cost that is not feasible for smaller businesses[11].

A holistic approach to pandemic prevention will need to also consider livestock as hosts or carriers of potential zoonoses and which interact with wild animals to amplify disease spillover risk. Zoonotic transmission from livestock occurs at a much higher rate than from wild animals, partly because of the much higher numbers of livestock and their much larger role in our food chains than wild animals[12 13]. Traceability is already used in domestic livestock and poultry supply chains, suggesting such approaches could be adapted to wild animal supply chains to minimise risks[14].

Mapping a supply chain and its risk points, which is the foundation for implementing traceability, offers a data-driven approach to assess the supply chain's safety and transparency and inform policy recommendations. From a zoonotic disease perspective, different forms of wild animal trade present different types and levels of risk; reducing these risks therefore calls for diverse solutions.

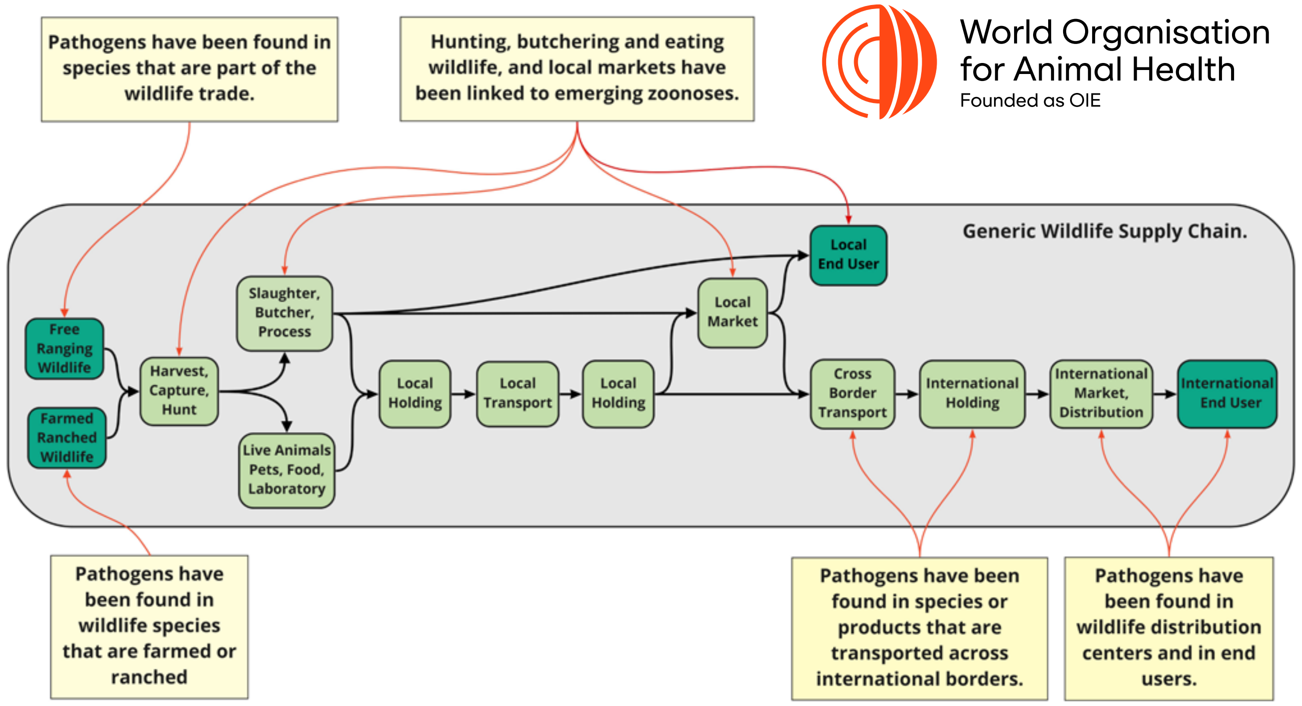
The authors of this Review considered three main use types for wild animal trade and consumption:

1. Wild animal meat
2. Wild animal-derived medicines, and
3. Live wild animals kept as pets or used for scientific research or display.

As noted in the Methodology & Limitations section, these three use types carry important differences in their relative risks of zoonotic disease transmission, while specific wild animal trade chains have further variations in risk. The traceability and supply chain management lens allows regulatory decisions to be evidence-based and context-specific to promote successful implementation and disease risk reduction.

FIGURE 1

Generic wildlife supply chain showing interfaces at which pathogens have been documented.
**NB: Local holding is also an important source point needing to be managed for potential disease risk (in possibly unsanitary conditions) and slaughtering of wild specimens can occur at any point up until the end-user. Source: Dr. John Berezowski, adapted from Stephen C, Berezowski J et al. (2021). (Link in footnote[15])*



PURPOSE AND OBJECTIVES

The emergence of SARS-CoV-2 brought increased attention to the potential zoonotic disease risks associated with trade in wild animals. As a result, the Wildlife TRAPS Project, a long-standing partnership between USAID, TRAFFIC and IUCN, refocused its objectives on finding solutions to prevent future pandemics by improving the safety and sustainability of legal wild animal trade. In tandem with efforts to support policy and regulatory reform, this is being addressed through two main workstreams:

1. Supply chain management and traceability to reduce risks and improve transparency from source to consumer in legal wild animal trade chains; and
2. Social and behaviour change (SBC) to direct consumers and stakeholders in wild animal trade toward safe, sustainable, legal products and practices.

Foundational research was conducted via a situation analysis of SBC messaging on wild animal trade and zoonotic disease risks, published in December 2021[16], and this Review on supply chain management and traceability. Both publications will support the planning of pilot interventions in countries engaged by TRAFFIC and its partners.

The primary objectives of this Review are to:

1. Review criteria for evaluating risks in wild animal supply chains, especially risks to human and animal health and safety;

2. Examine current national and international policy and regulatory contexts of traceability for trade in wild animal products, particularly for sanitary control measures and animal and human health and safety requirements;

3. Review current options for traceability data management tools that are simple and affordable:

- **a.** Consider which tools could best be adapted to managing less regulated wild animal trade chains in a developing country context;

4. Document and assess case study examples of wildlife trade chains already practising coordinated supply chain management and traceability with a focus on health risk reduction:

- **a.** Gather best practices and lessons learned;
- **b.** Identify key actors (government, non-government, private sector, and standard-holding organisations) for:
  - **i.** Risk mitigation at critical points in supply chains;
  - **ii.** Influence and willingness to engage;

5. Analyse lessons learned from relevant wildlife supply chain management and traceability initiatives to date;

6. Determine gaps and opportunities:

- **a.** Outline priorities for pilot projects to reduce zoonotic disease risks

7. Recommend what could be adapted or better implemented and enforced to mitigate risks of zoonotic disease transmission in wild animal supply chains.

METHODOLOGY AND LIMITATIONS

This review was conducted through primary and secondary research using multiple methods. Primary components included individual and group discussions with supply chain management experts and stakeholders. Secondary elements focused on a desk-based literature review of online reports and publications from NGOs, IGOs, national government authorities, scientific journals, and media outlets. A bibliography for the literature review is included in Annex II.

The authors note three main limitations of this Review. Whereas this Review was initially intended to consider wild animal supply chain management through the three lenses of safety, sustainability, and legality, one limitation was that the examples reviewed focused primarily on health risks and mitigation ('safety').

In drafting this Review, the authors considered three major categories of wild animal use: wild animal meat, wild animal-derived medicines, and live animals kept as pets or for display or scientific research. A second limitation of this Review is that its case study examples focus mainly on trade chains for wild animal meat. These wild meat trade chains include live animals early in the chain and meat products at the consumer end. Food production is a particularly relevant use type based on the varying risks of pathogen transmission from handling live animals, meat processing, and meat consumption. Food safety is a well-explored lens for traceability and disease risk reduction. Wild animal-derived medicines, in contrast, tend to be highly processed and therefore carry fewer risks of zoonotic pathogen transmission to consumers compared with meat, but may still have important risks when production involves live animals and unprocessed animal parts. Lastly, since human interactions with live wild animals are an important risk interface, there is a need to further investigate live wild animal trade chains for exotic pets, display, and scientific research. This Review found the most available references related to wild meat trade compared to the other use types, hence its focus.

A third limitation was in bridging the gap between lessons learned from established supply chain management mechanisms in highly regulated trades, and the situation of wild animal trade in less developed countries. Differential factors could include less government capacity for monitoring animal health linked to wildlife trade, in conjunction with varying levels of regulation, compliance and enforcement for wild animal trade. The selected case studies provide a starting point for assessing wild animal supply chain management, but in relation to the great diversity in global wild animal trade systems, they represent only a part of the overall situation. Efforts to address these limitations included in-depth discussions with experts and stakeholders regarding the less regulated wild animal supply chains throughout Asia and Africa and experts in animal and human health. A list of individuals interviewed can be found in Annex III.

EVALUATING SUPPLY CHAIN RISK FACTORS

The diversity of legal wild animal trade in different countries calls for informed, context-specific solutions. In assessing the suitability of supply chain management and traceability interventions to improve the safety and sustainability of a particular wild animal supply chain, it is important to evaluate the risks specific to the species, product or form in trade, and the number and type of transaction points that involve human-animal interfaces from source to end-user.

A February 2021 report by the World Wide Fund for Nature (WWF) on "Assessing risk factors for viral disease emergence within the wildlife trade" [17] groups the potential risks of zoonotic spillover and disease emergence within three categories, with several questions to guide assessment:

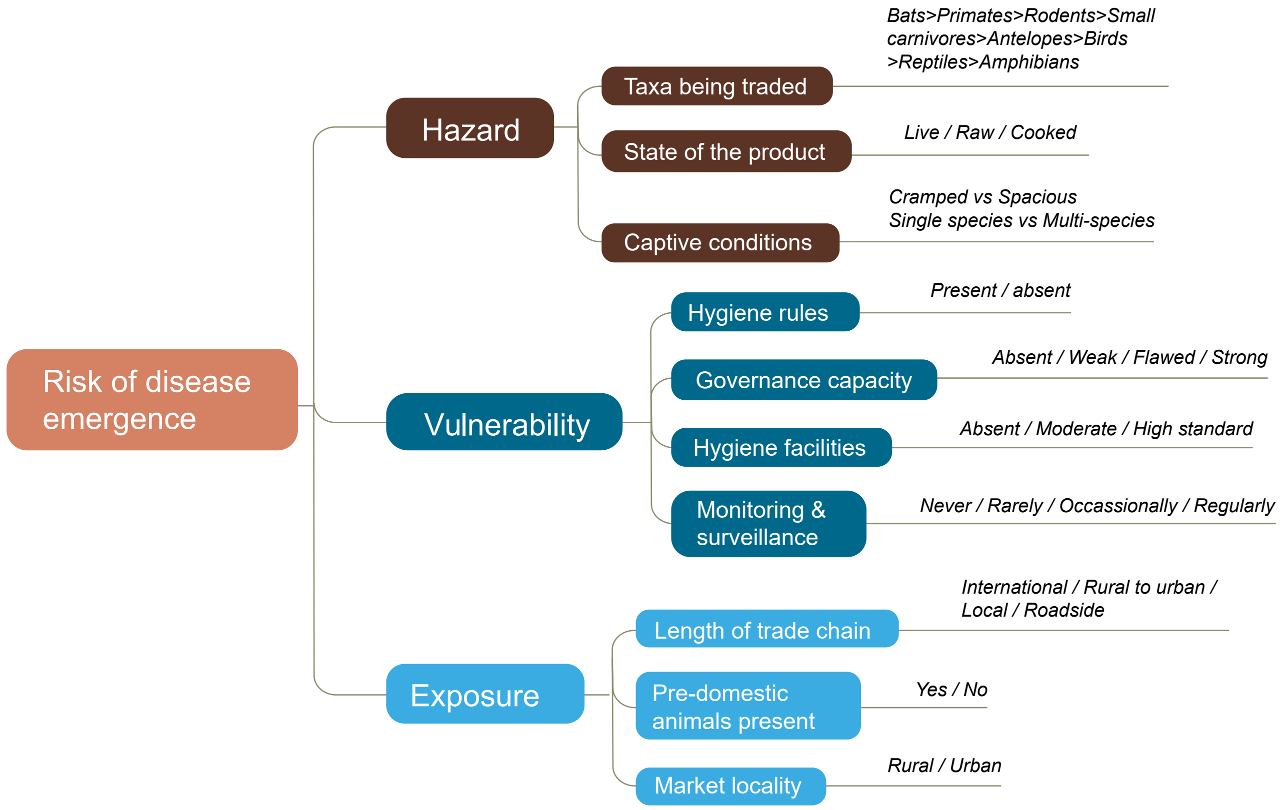
1. Hazard:
- **a.** What is the animal species' phylogenetic proximity to humans?
- **b.** Have they been known to carry zoonotic diseases in the past?
- **c.** How many different species are involved?
- **d.** Are the animal products in trade alive, raw, cooked, or a mixture of these?
- **e.** Under what conditions are the animals being kept?

2. Vulnerability:
- **a.** Are there hygiene rules at the market?
- **b.** How good is the government's capacity to fairly enforce policies, rules and regulations?
- **c.** What is the standard of washing facilities in processing facilities and markets?
- **d.** How often does disease testing, surveillance, monitoring and evaluation take place?

3. Exposure:
- **a.** How long is the supply chain?
- **b.** Were any of the species taken from a deforestation frontier zone?
- **c.** Is it a rural or an urban market?

FIGURE 2

The risk of zoonotic disease emergence and spillover can be assessed as a function of three dimensions: hazard, vulnerability, and exposure. Each of the three dimensions has three to four sub-variables, resulting in a composite risk score. Source: WWF (see link in footnote [18])

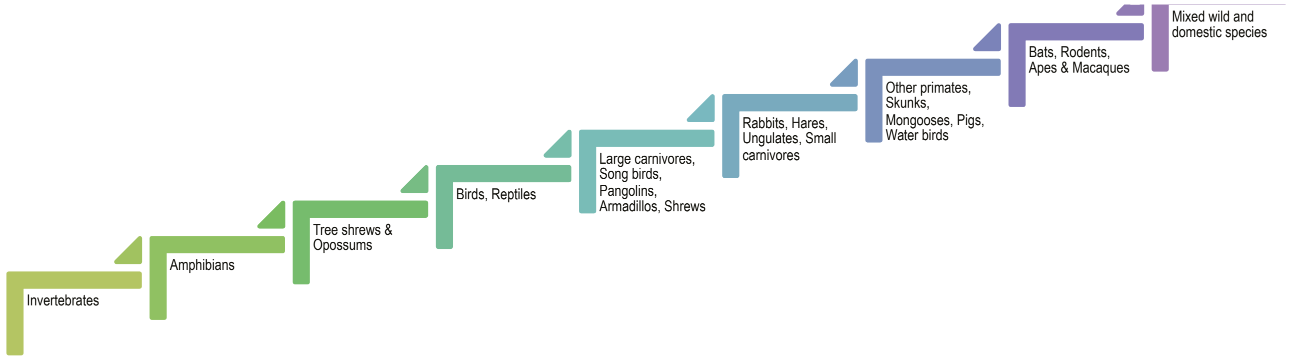


In carrying out this type of qualitative risk assessment, WWF recommends several foundational principles to keep in mind[19] :

- **i.** Mammals and birds are the highest risk taxa for disease spillover to humans, especially bats, rodents, and primates;
- **ii.** Live animals pose a greater risk for disease emergence than dead animals. Smoked, dried, fermented, and frozen carcasses have not been shown to transmit pathogens;
- **iii.** Longer trade chains carry greater risks and more chances for viral amplification:
  - **a.** Some animals, such as Malayan pangolins, showed no sign of coronavirus when seized in their country of origin[20], but contained coronaviruses closely related to SARS-CoV-2 when seized at the end of their trade route[21]. Farmed rodents and porcupines in Viet Nam already had avian and bat coronaviruses at the farm level, but the presence of these coronaviruses increased 10-fold at the restaurant level at the end of the trade chain[22];
- **iv.** Mixing live wild and domestic species increases the risk of transmission at any point in the trade chain, but especially in live animal markets;
- **v.** Weak governance and poor market infrastructure increase risk:
  - **a.** Africa and Asia have a large informal food sector that is not regulated and does not follow central government legislation on hygiene;
- **vi.** The most vulnerable people include:
  - **a.** Hunters in the forest who come into contact with live animals;
  - **b.** Food handlers living near, or working in, live animal markets;
  - **c.** Staff and customers in contact with caged live animals in a restaurant;
- **vii.** Varying effects of market size on risk:
  - **a.** Small rural markets risk exposure to small numbers of people but may have poorer hygiene oversight;
  - **b.** Big urban markets risk exposure to more people but may have stricter hygiene monitoring and enforcement[23].

FIGURE 3

A proposed hazard hierarchy of species in trade. Source: WWF (see link in footnote[24])



INTERGOVERNMENTAL GUIDANCE FOR RISK EVALUATION

In evaluating risks along the supply chain, the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) recommends identifying which areas of the trade are disease risk-free versus which areas have higher risk levels to tailor monitoring efforts[25]. This allows limited budgets and staff capacity to be applied where they can be most effective. Priority monitoring points may also look for bottlenecks of compliance activity in the supply chain, such as crucial processing or collection points. The USAID-funded Targeting Natural Resource Corruption[26] (TNRC) project provides a helpful example for mapping the various risk points along the length of a wild animal supply chain. The risk lens for this TNRC work was in mapping corruption, but the approach can easily be adapted to mapping disease risk points.

In December 2020, the Tripartite organisations (the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), and the World Organisation for Animal Health (formerly OIE, recently renamed WOAH)) released their Joint Risk Assessment Operational Tool[27], which provides guidance on how to set up a zoonotic disease risk self-assessment at the national level. This kind of scientific framework enables the development of sound risk management policy and communications, bringing together cross-sectoral expertise from the animal health, human health, and environmental health communities for a holistic One Health response. Even beyond the wild animal trade, no product or supply chain can be guaranteed 100% safe, but a robust risk assessment allows risks to be managed to an acceptable standard.

Streetside vendor selling chicken and pork meat in Hanoi, Viet Nam

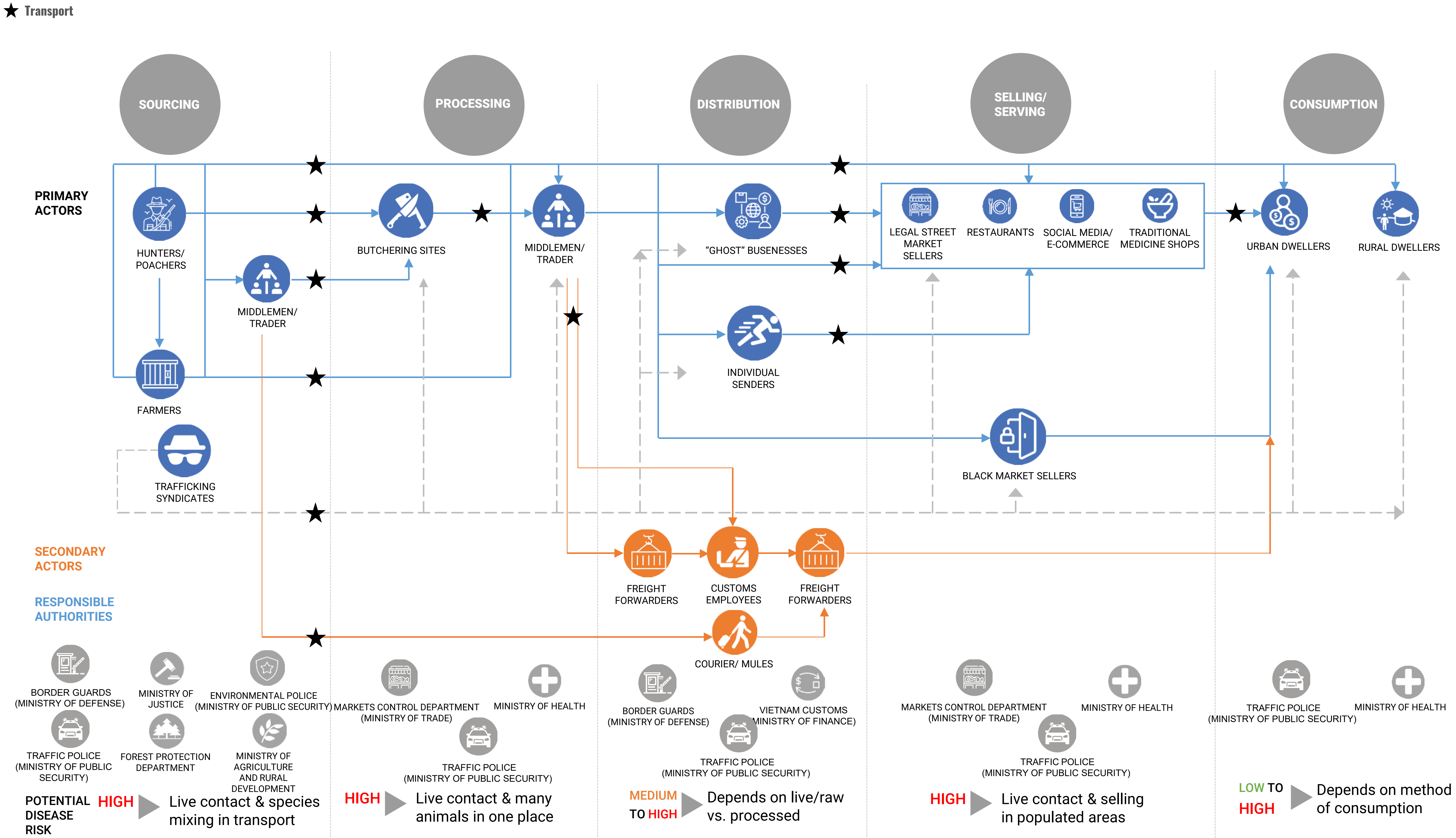
EVALUATING RISKS AT THE NATIONAL LEVEL: VIET NAM

In Viet Nam, TRAFFIC has conducted an initial trade chain analysis of wild animals and their products used for meat and attributed medicinal benefits (i.e., formal and informal traditional medicine use). The research focused on six groups of animals commonly traded for these uses in Viet Nam, which are known to carry zoonotic pathogens: bats, rats, macaques, pangolins, civets, and birds. This national-level qualitative analysis drew from 30 in-depth interviews conducted with wildlife trade experts and stakeholders in Viet Nam.

From the interviews, the researchers mapped the trade chain from source (either from the wild or from captive farming facilities) to consumer. Sections of the trade chain are mapped alongside the relevant government authorities that have jurisdictional oversight at each stage in the trade chain, as well as the relative risks of potential zoonotic disease transmission at each point in the chain. This understanding allowed the researchers to assess opportunities for targeted interventions to reduce zoonotic disease risks along the trade chain. The initial analysis and findings are now being validated by the same group of experts. Once the research is finalised, it will serve as a foundation for designing projects to improve the safety and sustainability of legal wildlife trade in Viet Nam and will provide a model for similar trade chain mapping and interventions in other countries where TRAFFIC works.

FIGURE 4

Map of Viet Nam's wild animal trade chain for meat and medicinal uses. Includes notes on the government authorities responsible at each stage in the trade and qualitative estimates of the relative risk of zoonotic disease transmission from a wild animal to a human at each stage. Following this expert elicitation, risk pathways would need to be further evaluated based on types of species in trade, magnitude of trade, human behaviours and practices, hazard identification and zoonotic disease surveillance, and other contextual factors at different points in the trade chain. Source: TRAFFIC and Prophet, based on expert interview responses



REGULATORY CONTEXTS FOR TRACEABILITY

As illustrated by the Viet Nam wild animal trade chain mapping, understanding the structure and steps in the chain for animals and products from consumer to source is an essential step in evaluating and managing the risks of that chain[28]. This next section assesses the different regulatory contexts in which traceability may operate.

Traceability systems operate within two primary contexts: mandatory and voluntary.

Mandatory traceability systems are implemented by governments, such as requiring permits to export products of a particular species. **Voluntary traceability systems** are often implemented by private sector actors to ensure product quality, align with companies' values, and capitalise on business incentives for product traceability[29].

REGULATIONS AT THE NATIONAL LEVEL

Traceability is an important tool for monitoring risks across different wild animal trade types, whether for food, medicine, pets, display, or research. Existing traceability practices for domesticated livestock make food traceability a helpful starting point to understand regulatory contexts. The responsibility for implementing and monitoring food traceability requirements may be carried out by national governments, local governments, or industry associations. National systems for mandatory livestock identification and traceability proliferated in the late 1990s and early 2000s in response to the spread of bovine spongiform encephalopathy, or 'mad cow disease'[30]. Where industry-led programmes are prevalent, these typically precede the establishment of government-led traceability systems. Food traceability systems are less common in developing countries where food security remains an issue; access to sufficient quantities of food is prioritised over concerns for the food's quality[31].

In comparing those countries that are furthest along in the development of food traceability systems, several notable features emerge.

Historically, Canada and the United States have had less government-led traceability and more reliance on voluntary industry-led traceability. China has rapidly accelerated its government-led traceability requirements over the past decade but still lags behind European countries[32]. The European Union (EU) countries stand out as having the world's strongest and most transparent food safety and traceability practices, both for domestic products and imports[33]. EU legislation requires that all food and feed products be traceable; importers must be able to identify the exporting entity in the product's country of origin, and businesses must be able to locate both one step back along the supply chain (towards the source) and one step forward (towards the final consumer)[34].

Beyond the EU, national food traceability requirements tend to be limited to specific commodities. Japan and Norway, for example, require tracing for animals and animal products, but few other foods and commodities have mandatory traceability[35]. Globally, traceability requirements for livestock are much more evolved than traceability for wild-harvested seafood, particularly seafood sourced from developing countries. Thus far, there are fewer examples of traceability for terrestrial wild animal products, hence the potential to carry over systems developed for livestock. For instance, in 2013 New Zealand extended its cattle identification and traceability requirements to deer .


Factory for the production of sausages

REGULATIONS AT THE INTERNATIONAL LEVEL

The Parties to the Convention on International Trade in Endangered Species (CITES) have assessed the context in which traceability should be considered as a tool for greater monitoring of a supply chain and have offered guidance to Parties in the use of traceability systems[37]. A review[38] that assessed the complexity of CITES-listed species in international supply chains and the technical difficulties in dealing with wild animal products across taxonomic groups concluded traceability needed to be crafted to the needs of each particular supply chain.

The CPTPP chapter on Sanitary and Phytosanitary Measures offers regulatory guidance for international supply chains. For international trade, sanitary measures must be equivalent between exporting and importing countries. Each country should conduct a risk assessment based on scientific data, using both quantitative and qualitative information. This risk analysis should be documented for public review and comments by other interested countries. Proposed sanitary measures and their legal basis should also be publicly available and open for public comment [39].

Under the CPTPP, importing countries can audit exporting countries' authorities and inspection systems and conduct on-site inspections of facilities if appropriate. In the case of an audit, the auditing party should allow the audited party to review and comment on the findings before taking action. Exporting countries must notify importing countries in the following situations:

- A significant sanitary risk related to an exported good
- Urgent national changes in animal health that may affect trade
- Substantial changes in the status of a regional pest or disease
- New scientific findings that would affect the regulatory response
- Significant changes in food safety or disease management/control/eradication policies that affect trade[40]

VOLUNTARY SYSTEMS

Voluntary traceability systems are often implemented by the private sector to enhance and standardise companies' own sourcing and production practices and market these good practices to consumers. Examples for wild-sourced animals and plants include the Marine Stewardship Council (MSC) and FairWild. These two systems, MSC for seafood and FairWild for plants, have the potential to be adapted to trade in wild terrestrial mammals and birds but are not currently used as such, hence both are explored further in Annex I. Governments can also play an important role in voluntary traceability systems, as shown via organic farming standards. Organic standards were initially developed by the private sector, but some were later regulated by governments to help improve their reach and public credibility, as is the case in the European Union and the United States[41]. A potential disadvantage of government involvement in voluntary standards is that the standards need to be agreed upon by a more diverse set of stakeholders and become more challenging to revise[42].

TRACEABILITY MECHANISMS TO CONSIDER FOR TRADE CHAINS IN WILD MAMMALS AND BIRDS

This next section moves from the potential regulatory contexts for traceability to assessing specific methods and tools that could be adapted for use in different wild animal trade systems. The Hazard Analysis and Critical Control Points (HACCP) system was studied for its role in mitigating health risks in food supply chains. The use of blockchain technology was considered for its potential to ensure that supply chain data is both accessible and free from unauthorised modifications. Mobile applications for capturing supply chain data were likewise reviewed for accessibility, practicality, and potential affordability.

ASSESSING AND ADDRESSING SYSTEMIC RISKS: HACCP

HACCP is a leading international set of principles for assessing and mitigating the health safety issues of a particular product and its supply chain. HACCP focuses on prevention along the supply chain from primary production to final consumption[43].
The system considers hazards as pathogens or chemicals with the potential to cause harm to human health, and risks as the likelihood and severity of health effects these hazards could cause[44]. Animal health, both in testing animals and animal products for pathogens, is also an important component of HACCP[45]. Hazards, risks, processes, and actors along the supply chain are analysed to identify and manage the critical control points for ensuring product safety. Developed in the 1960s, HACCP is widely used for food production and other industries where health safety is critical, such as pharmaceuticals and cosmetics. It is endorsed by FAO, WHO, and national government authorities such as the United States Food and Drug Administration[46].

HACCP has been broadly applied to international livestock trade, and its principles could be similarly applied to improve the management of wild animal trade[47]. The nature of HACCP enables evidence-based, context-specific solutions for disease risk reduction. For example, when used to control foot and mouth disease in cattle, HACCP has empowered local stakeholders to engage in risk management while preserving their livelihoods[48]. It is important to note that HACCP focuses on reducing risks from known hazards rather than reducing risks from unknown novel pathogens. Using the Critical Control Point approach to identify potential risk points and prioritise appropriate mitigation measures would provide a practical foundation; however, adaptations would be needed to account for the variations between different wild animal trade contexts.

Basic steps for application of HACCP in a supply chain include[49]:

1. Describe the product: its composition, any treatments, its durability, storage conditions, etc.
2. Identify the product's intended use by the end consumer
3. Map the supply chain, from primary production to end-use, and cross-check this mapping with experts and stakeholders
4. List all potential hazards along the supply chain and consider what control measures are needed
5. Determine the Critical Control Points
6. Set a quantifiable limit for compliance at each Critical Control Point that allows time for corrective action before the limit is breached
7. Establish a monitoring system for each Critical Control Point
8. Establish corrective actions
9. Establish verification procedures to ensure that the HACCP system is working effectively, such as product testing or internal audits
10. Establish documentation and record-keeping.


Animal transporter truck

IMPROVING DATA INTEGRITY: BLOCKCHAIN

Once a set of principles for disease risk monitoring and management is in place, an important next step is to ensure that the data gathered remains both accurate and accessible across the supply chain. Blockchain technology is an increasingly popular tool to secure and disseminate supply chain traceability data.

Blockchain is a distributed digital ledger that can store data of any kind. Its best-known use is for cryptocurrencies like Bitcoin, but it has a range of other applications, including monitoring supply chains. Using blockchain technology can help to improve the transparency and traceability of supply chain data and make the data difficult to tamper with because the database itself is fully decentralised. Whereas traditional databases may rely on one location and administrator, identical copies of a blockchain database are stored on multiple computers across a network. Before any new information can be added to the database, a majority of computers throughout the network must verify the data's legitimacy[50]. This verification can help to flag incorrect information to enable prompt investigation of any fraudulent activity that might pose risks to the supply chain's safety, sustainability, and legality.

Blockchain technology is an increasingly popular tool to secure and disseminate supply chain traceability data.

CASE STUDY – THE FISHCOIN PROJECT[51]

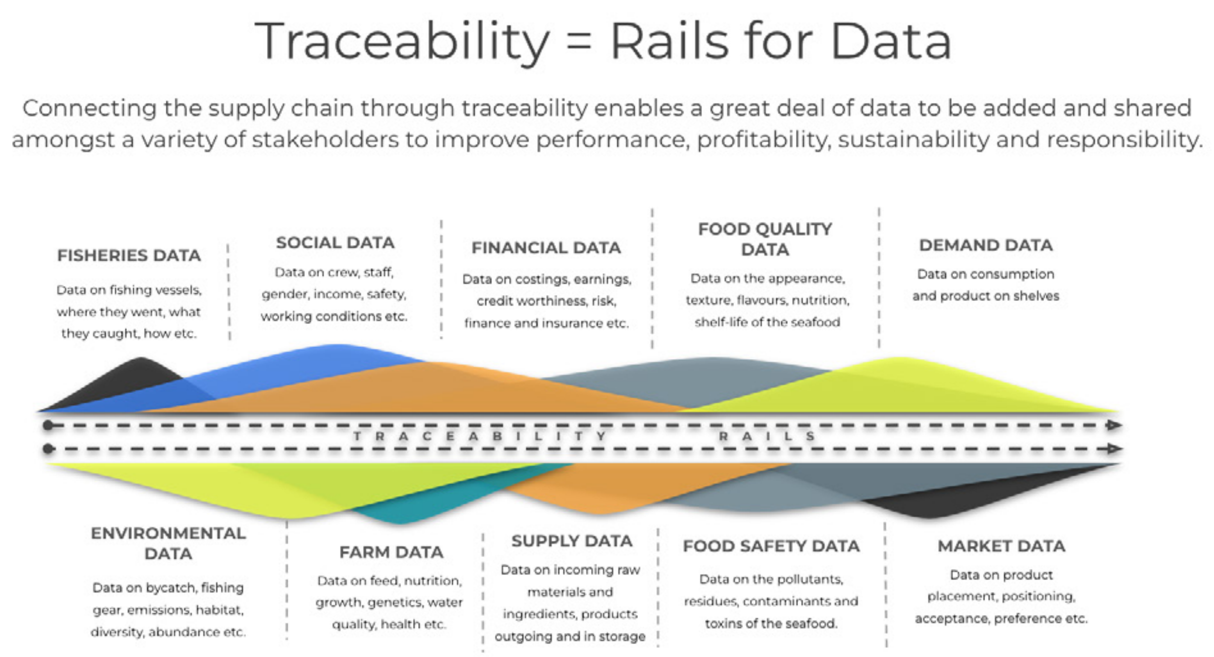
Building on the mFish initiative of the US State Department, mFish-Trace is a multilingual blockchain-based traceability system that rewards fishers for inputting data with Fishcoin tokens. These tokens can then be redeemed for mobile top-ups; other goods and services may be added as token redemption options in the future. The Fishcoin system shows that blockchain technology does not need to be expensive or consume substantial electricity, as with Bitcoin. The base system uses the Stellar[52] blockchain, which costs a fraction of a cent per transaction, and the Trace Protocol behind Fishcoin is blockchain system agnostic. The Fishcoin Project developers simplified the application's coding to allow it to operate on a 2G cellular network[53].

The business model for traceability is sometimes lacking, as it is often unclear which actors in the trade should pay for the costs of data collection and storage and who should own the data. When the Fishcoin Project developers first released their mFish.co[54] traceability application, there was no incentive for fishers to share their data despite the App being free to use. Tokens now reward the fishers for their data, and the fishers choose how the data is shared. A project led by Herriot-Watt University is exploring how sensors on fishing nets can further support the cost of traceability. These sensors enable precision fishing while simultaneously gathering data for climate change research. Fishcoin tokens pay for this technology, so consumers who are willing to pay a premium for climate-smart seafood support the cost, and it does not fall solely on fishers[55].

Although blockchain can facilitate tracing a supply chain, enabling faster and more reliable data sharing, it is not a one-size-fits-all solution. More important to traceability than implementing advanced technology is to close information gaps in the supply chain through improved management practices and closer collaboration among actors along the chain. To effectively trace the whole supply chain, actors should first share information using the same data model[56]. This initial commitment to collaboration, if successful, can serve as an entry point to the adoption of blockchain.

FIGURE 5

Numerous forms of data can be shared via traceability. Source: Alistair Douglas



GUIDING CONSUMERS: STANDARDS FOR TRACEABILITY

To improve and standardise product traceability and market this traceability to consumers, certification schemes like the Forest Stewardship Council (FSC) and Fair Trade have proliferated in recent decades[57]. Their easily recognisable, widespread labels can be a valuable guide to conscientious consumers searching for products with added value for sustainable sourcing, workers' rights, and other production concerns.

Large-scale certifications, however, tend to favour big producers. For certifications that rely on third-party auditing to verify the supply chain data collected, audits can be prohibitively expensive without a critical mass of sales. Such voluntary standards have thus far faced barriers to adoption in developing countries, particularly for small-scale producers[58,59]. Recognising these challenges, standards such as MSC and FairWild (both covered in more detail in Annex I) have introduced programmes for producers to gradually progress towards certification over their first several years of engagement.

Artisanal shark fishermen in the Republic of Congo

INCREASING ACCESSIBILITY FOR STAKEHOLDERS: TRACEABILITY APPS

As mobile phones have become common even in developing regions, mobile applications present an accessible, low-cost option for small-scale producers to capture their supply chain data and share this with merchants and consumers without the expense of certification. This can enable a more direct, personal connection between the consumer, the product, and the producer, and is customisable to recognise the unique efforts of the producer beyond compliance with a single set of standards. This customisation allows high-achieving, small-scale producers to market their goods at a premium and recover the costs of their extra efforts, and allows consumers to choose the product that best matches their needs and values[60 61].

Third-party certifications are still an important goal for producers and other stakeholders in trade to work towards, as these systems strengthen quality control and enable objective, independent evaluations of trade practices. Using a traceability App can be a helpful first step toward engaging with the more rigorous production and data management requirements of certification.

An example of a mobile traceability App for wild-harvested sharks is SharkTrace. It is worth noting that this kind of App can easily be adapted to different supply chains and product types, including terrestrial wild animal species, by changing the data elements collected; the App is simply a tool for collecting data.

SHARKTRACE

SharkTrace[62] is a mobile App-based traceability tool that tags and tracks shark and ray products from capture through to consumption. It aims to enable governments and traders to verify that shark and ray products are from legal, sustainable sources and help regulators, including those implementing CITES, exclude products not meeting these criteria.

SharkTrace consists of three unique Apps to enable traceability across the three main phases in the supply chain:

1. A vessel-based application for tracking sharks from the point of catch to landing at the wharf

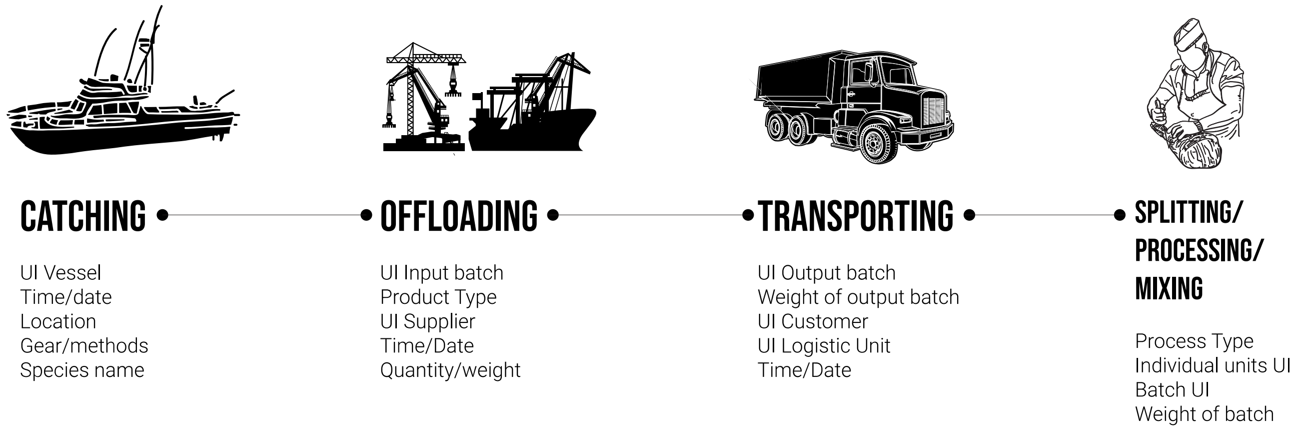
2. A factory application for the main processing stage, and

3. A transport application that covers the packaging and distribution stages.

The Apps are designed to work on the simplest and least expensive smartphones available. They can operate without cell phone reception to make them usable at sea, and the data will automatically sync once back in reception range.

FIGURE 6

The Key Data Elements (KDE) used in SharkTrace for each of the four Critical Tracking Events (CTE) throughout a shark product's journey. Source: TRAFFIC (see link in footnote)



For ease and reliability of data gathering, the SharkTrace system can produce tags for carcasses or more highly processed products with both a radio-frequency identification (RFID) tag and a visible tag. This combination of visible and invisible tags prevents the easy duplication of a single physical tag. A cloud-based application aggregates the data from the three different supply chain Apps each time a quick response (QR) code or barcode is scanned. Different permission levels for different users help prevent data tampering, and any differences in the data from one stage to another will alert the administrator with a red flag.

Several practical lessons gathered so far from the development and implementation of the SharkTrace traceability Apps are:

- The application and the technology and equipment it requires must be cost-effective to facilitate uptake;
- Any equipment needed (phones, tablets, tag readers/scanners) should be durable and suited to the environment in which it will be used;
- Tags should be cheap, reliable, single-use, and attachable to the carcass or product.

In developing SharkTrace, the harvesting and processing practices were examined to determine a) Which parts of the supply chain would best accommodate the capture of critical information, such as species, catch location, catching method, etc., and b) What were the most appropriate terms to be loaded into the Apps to allow users to select from dropdown menus. Such user options include viewing the App in the local language and selecting the different common names for species and the form of processed product. The Apps could be adapted to any type of supply chain across different taxa and could be adjusted for use in any language, enabling broad application beyond shark and ray products and extending to terrestrial species.

CASE STUDIES: WILD ANIMAL SUPPLY CHAINS MANAGING FOR DISEASE RISKS

The potential for extending the use of well-established systems used globally to ensure food safety, such as HACCP, to wild animal trade has been proposed as providing a way for some trade in wild animals to continue in a manner that addresses health risks to humans[63]. A first step to further the potential application and adoption of HACCP and similar approaches to disease risk management is to document and extract insight on how such frameworks could be used in the wild animal trade. Understanding the supply chain geography, including actors along the supply chain, the accompanying legislation, and the role of different government agencies and private sector participants will help define the potential for their practical application.

To examine the potential for using the HACCP approach to address disease risk imperatives associated with trade in wild animals, the following three case studies were selected to investigate established wildlife meat production systems in different contexts:

- the well-developed kangaroo industry in Australia
- the avian influenza-adapted ostrich industry in South Africa, and
- the long-standing hunting, consumption and trade of venison in France.

Australia's kangaroo industry relies entirely on wild harvest, whereas South Africa's ostrich industry relies on closed-cycle captive breeding without introducing wild stock, and France's venison trade includes both wild harvest and some captive production. It is worth noting that these three case study examples are all relatively industrialised and operate in country contexts with well-developed animal health sectors. These countries also have well-developed biosecurity regulations for livestock production, which may serve as an important basis for regulating biosecurity in wild animal trade. In contrast, much of the global trade in wild animals involves countries with limited resources for animal health and comparatively less regulation for biosecurity in animal production. These case studies help assess good practices to work towards (albeit still with room for improvement), but their lessons will require adaptation to the contexts of countries with less developed biosecurity regulations. The broadly applicable lesson that these case studies illustrate is the importance of establishing critical control points to monitor and manage risks along the supply chain; this step is essential to enabling safe and sustainable legal wild animal trade to occur.

The objectives of each case study were to describe:

- The overall structure of the supply chain for the species and traded commodities
- he key actors and stakeholders along the supply chain
- The Critical Control Points along the supply chain and the associated responsibilities of government authorities and other actors, and
- The legislation and government departments responsible for implementation.

Considerable detail was collected on each case study, including lists of relevant laws, practices, and guidelines. What follows are the key points related to this Review's focus on supply chain management and traceability for improved safety and sustainability of legal wild animal trade, with particular attention to health and safety.

FIGURE 7

From left to right, an eastern grey kangaroo, a South African ostrich farm, and a red deer

AUSTRALIA'S KANGAROO MEAT INDUSTRY

CONTEXT OF AUSTRALIA'S KANGAROO MEAT TRADE

The Australian kangaroo meat industry is characterised by the harvest of four key species: red kangaroo (*Macropus rufus*), western grey kangaroo (*Macropus fuliginosus*), eastern grey kangaroo (*Macropus giganteus*), and common wallaroo (*Macropus robustus*). There are currently four abattoirs operating as export establishments and the industry currently has market access to approximately 60 overseas markets[64]. This case study details some of the health safety concerns for the kangaroo meat industry, namely *Salmonella*, *Escherichia coli* and *Toxoplasma gondii*, and the key control points regulated in HACCP systems across the industry.

There is a long history of consumption of kangaroo meat by Aboriginal Australians dating back 40,000 years[65]. In 1788, British colonisation began on the continent, and colonists also began hunting and consuming kangaroos[66]. Concerns about kangaroo meat consumption emerged in the 1860s when kangaroo meat came to be considered high in worm infestations and was banned under the health act[67]. However, concern over worms in kangaroo meat was later determined to be unfounded[68].

In the 1950s, the market for kangaroo meat began to re-emerge[69 70] and in the 1960s, research focused on kangaroo biology and understanding its safety for consumption[71]. In the 1970s, kangaroo meat began to be used for domestic pet food. Urbanisation at the time contributed to a growing interest in consuming kangaroo meat and a subsequent interest in farming kangaroos.

Kangaroo farming, however, was deemed unfeasible due to high costs and challenges in husbandry[72 73 74 75]. In 1988, the first regulations for the harvest of wild kangaroo were released, alongside guidance for kangaroo meat processing. A code of practice for all game meat production (including kangaroos) was also established[76]. From 1990, kangaroo meat sold commercially was required to adhere to these regulations[77].

HACCP was first applied to Australia's kangaroo meat industry in 1996, and in 1997 the Commonwealth Scientific and Industrial Research Organisation (CSIRO) released the Australian Standard for Production of Game Meat for Human Consumption[78]. In 2007, the standard was updated to create the Australian Standard for the Hygienic Production of Wild Game Meat for Human Consumption[79] (which includes kangaroo). The industry codified its welfare standard in 2008 by releasing the National Code for Humane Shooting of Kangaroos and Wallabies.
The code was revised and approved by the Australian Government in 2020 as the National Code of Practice for the Humane Shooting of Kangaroos and Wallabies for Commercial Purposes[80]. Australia released regulations for game meat export procedures and standards in 2010[81]. In early 2021, Australia opened consultation from the industry, stakeholders, and the public for changes in its export regulations. This consultation resulted in revisions in export regulation for game meat released in July 2021[82]. However, standards of meat processing still refer to the 2007 Australian Standard for the Hygienic Production of Wild Game Meat for Human Consumption[83].

KANGAROO MEAT TRADE'S HAZARDS AND HISTORY OF DISEASE OUTBREAKS

Scientific evidence has shown that kangaroos are susceptible to some of the same infections from pathogens present in other animals produced for meat, such as cattle and lamb. There have been no recorded zoonotic diseases or food-borne illnesses transmitted to humans from consuming kangaroo meat[84]. There have been rare cases of zoonotic transmission of Q fever (a disease caused by the bacterium *Coxiella burnetii*), from live kangaroos to humans via exposure to kangaroo faeces, Q fever is common in livestock species but may also infect kangaroos. There have been no cases of Q fever transmission from meat.

Similar to requirements for processing animals such as cattle and sheep, the Australian Government requires regular monitoring for indicators of processing hygiene (aerobic plate count (APC) and generic Escherichia coli) and pathogens (Salmonella)[85]. Observed Salmonella prevalence on kangaroo carcasses is very low, with only one instance of detection in the 12 months to May 2021[86]. There were claims in 2009 and 2011 that kangaroo meat shipments to the Russian Federation contained *Escherichia coli*, which led Russia to halt imports[87]. In response to Russia's withdrawal from the export market, Australia conducted training initiatives to improve quality and hygiene standards in the kangaroo meat industry[88 89]. The latest export regulation revision (Export Control Act 2020) and the Microbiological Manual for Sampling and Testing of Export Meat and Meat Products (2021) also include updated guidelines and methods of testing. *Toxoplasma gondii* is another contaminant of concern and has also been identified as a food safety risk for domestic red meat and unwashed fruit and vegetables. Testing for *T. gondii* is not included in guidelines as proper freezing and cooking inactivate the parasite [90 91 92].

STEPS IN THE KANGAROO MEAT SUPPLY CHAIN WITH CORRESPONDING HAZARDS AND CCPS

The kangaroo meat industry is regulated throughout its supply chain by several governing bodies (see Figure 9).

The phases within kangaroo meat harvesting can be grouped into:

A) The pre-harvest phase, which includes:
- **1)** Population management of kangaroo and quota setting
- **2)** Pre-harvest training and certification for humane shooting and proper handling

B) The harvest phase, which includes:
- **1)** Field dressing
- **2)** Transportation
- **3)** Storage in chillers before transportation to processing centres

C) The meat processing phase, which includes:
- **1)** Carcass inspection
- **2)** Game meat processing
- **3)** Game meat packaging

Uses of kangaroo meat are determined based on meat quality and may include human consumption, pet food, and pharmaceutical purposes[93]. Based on meat establishment certification and destination, the meat is either used for domestic consumption or is exported to countries that accept kangaroo meat and meat products produced at export-registered establishments.

The entire process of the production chain can be found in Figure 8.

A. Pre-Harvest Phase
A.1. Kangaroo population monitoring and quota setting
Relevant state governments and the national government's Wildlife Trade Office monitor the 'key species' of kangaroo population for the purpose of commercial harvest, and the population count is used to set annual harvest quotas[94]. The annual quota is dependent on a variety of criteria, including aerial surveys and population management plans, and may vary according to changes in kangaroo populations which may be impacted by events such as droughts, bushfires, or the presence of disease[95 96]. The occurrence of any such event would halt all harvest activities until the relevant state government deems that field conditions are suitable for harvest to continue[97]. Harvesters must purchase hunting tags, and all sold and unsold tags are recorded. More information on hunting tags can be found in the later sub-section on current traceability measures.

A.2. Pre-harvest training and certification
To ensure field harvesters are equipped with the skills for humane harvest, standardised field dressing, and transportation of kangaroos (as well as properly equipped vehicles) to prevent mishandling and contamination, field harvesters are required to be certified through multiple courses. These include courses on humane animal shooting, field dressing, transportation, and storage before sending carcasses to the processors. Field harvesters must maintain a shooting and harvesting license, renewed every five years.

B. Harvest phase
Kangaroo harvesting is typically conducted at night (when kangaroos are more active[98] and when air temperatures are cooler) and must adhere to the Australian Standard for the Hygienic Production of Wild Game Meat for Human Consumption[99]. Harvest methods are based on the National Code for Humane Killing of Kangaroos and Wallabies[100]. Kangaroos must be head shot with a single shot, and carcasses are then tagged. The carcass is then field dressed, naturally bled, and hung. The skin is left on the carcass to avoid contamination. Post-harvest and field dressing, the carcasses are transported to field chillers, either when the transportation vehicle is full or two hours before sunrise. Carcasses are stored in sub-seven-degree celsius temperatures. These field chillers have temperature loggers installed to ensure that the temperature remains constant. During field harvest, there are no regular third-party inspections. Inspections may occur occasionally but may be opportunistic. Risk in this phase includes potential contamination due to mishandling of the carcass by field harvesters, with harvester certification courses and licenses intended to mitigate these risks. Adherence to field harvest procedures is commonly inferred from the condition of the carcass when arriving at meat processing establishments; an explanation of what is inspected is included in the subsequent section on carcass and meat inspections. During transportation, risk factors include the distance from harvest site to field chillers, from field chillers to meat processing establishments, and variations in temperature during harvest and transportation, which may increase contamination risks. The transport distance from field chillers to meat

processing establishments can be far, in some cases up to 800 km. Vehicles are required to use mobile chillers for transportation (which also have temperature loggers installed, like field chillers, to monitor and maintain a constant temperature). Each state has its own regulations and protocols to ensure food safety compliance. Following these protocols, field chillers and vehicles require accreditation and are regularly audited by food safety authorities of each state (e.g., Safe Food for Queensland, the Department of Environment, Climate Change and Water for New South Wales and Biosecurity SA for South Australia). The bulk of inspection for carcass contamination is done in the subsequent meat processing phase.

C. Meat processing

Standards of carcass handling at the meat processing stage differ based on the consumer market, but all establishments are required to comply with the Australian Standard for the Hygienic Production of Wild Game Meat for Human Consumption[101]. In addition to the domestic market, there are four establishments that are registered to process chilled and frozen kangaroo meat for export. Two are located in South Australia, one in New South Wales, and one in Queensland[102].

Each establishment is required to have a qualified meat safety inspector. For domestic establishments, meat inspectors are either state officials or employed third parties overseen by the State Represented Authority (SRA) (mostly State food safety departments) and are on-site to examine each carcass before shipment[103]. For exporting establishments, meat inspectors are on-site daily and are overseen by a veterinarian and the Federal Department of Agriculture, Fisheries, and Forestry.

C.1 Carcass and meat inspections

Post-mortem inspection of all carcasses before entering the processing plant occurs daily for all establishments, with a yearly audit of the hygiene of equipment and procedures for all establishments. An annual audit is a minimum requirement; however, audits commonly occur more frequently. For all establishments, meat inspectors are present on-site and perform a pre-inspection (to inspect for any issues that may have affected the animal before harvest) and verification of post-mortem inspection and processor hygiene practices. If an animal was not headshot, it is not eligible for processing[104]. Every carcass is inspected and microbial testing is performed to confirm processor hygiene.

Meat inspectors visually check the carcasses to ensure no physical abnormalities. This includes checking for bruises, lesions, and any other visible abnormalities along with inspection to ensure implementation of proper harvest method and checking for the presence of disease. Some establishments perform additional inspection using an x-ray machine and metal detectors to ensure there is no damage to the carcass or metal residue from improper harvest, transportation or handling. All inspections are done to ensure adherence to the Australian Standard of Game Meat[105]. The inspections determine both the quality and the destination of the meat. Decisions are made on whether the carcass and its parts would be suitable for one of the following:

- Passed for human consumption
- Retained for other examinations before final disposition (i.e., temporarily kept aside for further examinations to determine how it should be treated)
- Unfit for human consumption and may be recovered for animal food
- Unfit for human consumption and may be recovered for pharmaceutical material (e.g., pericardium, valves and cartilage of kangaroos are used for some medical applications[106])
- Condemned

For export meat, there are additional categories:

- Passed for human consumption and unsuitable for export
- Passed for human consumption and unsuitable for export to a specified country

Once the meat enters the category for animal food, it then follows the Australian standard for commercial pet food. Carcasses are tested for microbial contaminants based on Australia's export microbial manual for sampling and testing. Establishments are also responsible for the hygienic operations of their facilities, which are verified through assessment against Australian performance standards. Establishments are required to record all meat and hygiene inspection results and input the information into a national database to ensure record management and traceability. Data records are logged online into a Meat Export Data Collection (MEDC) System.

C.2 Performance of microbial testing

Carcasses are tested for microorganisms based on Australia's export microbial manual for sampling and testing[107]. The most commonly observed contaminants include *Salmonella*, *Escherichia coli* and APC. Microbial sampling is performed after the kangaroo is dressed (skinned) and before entering the meat processing area of the establishment. The Australian Government specifies carcass sampling frequency and performance criteria for *E. coli* and *Salmonella*. If monitoring results exceed performance criteria, the processing establishment must investigate the cause and implement corrective actions to ensure continued detections do not occur. Establishments are regularly audited. If establishments do not pass reaudit requirements, sanctions may include suspension or revocation (partial or full) of their establishment approval.

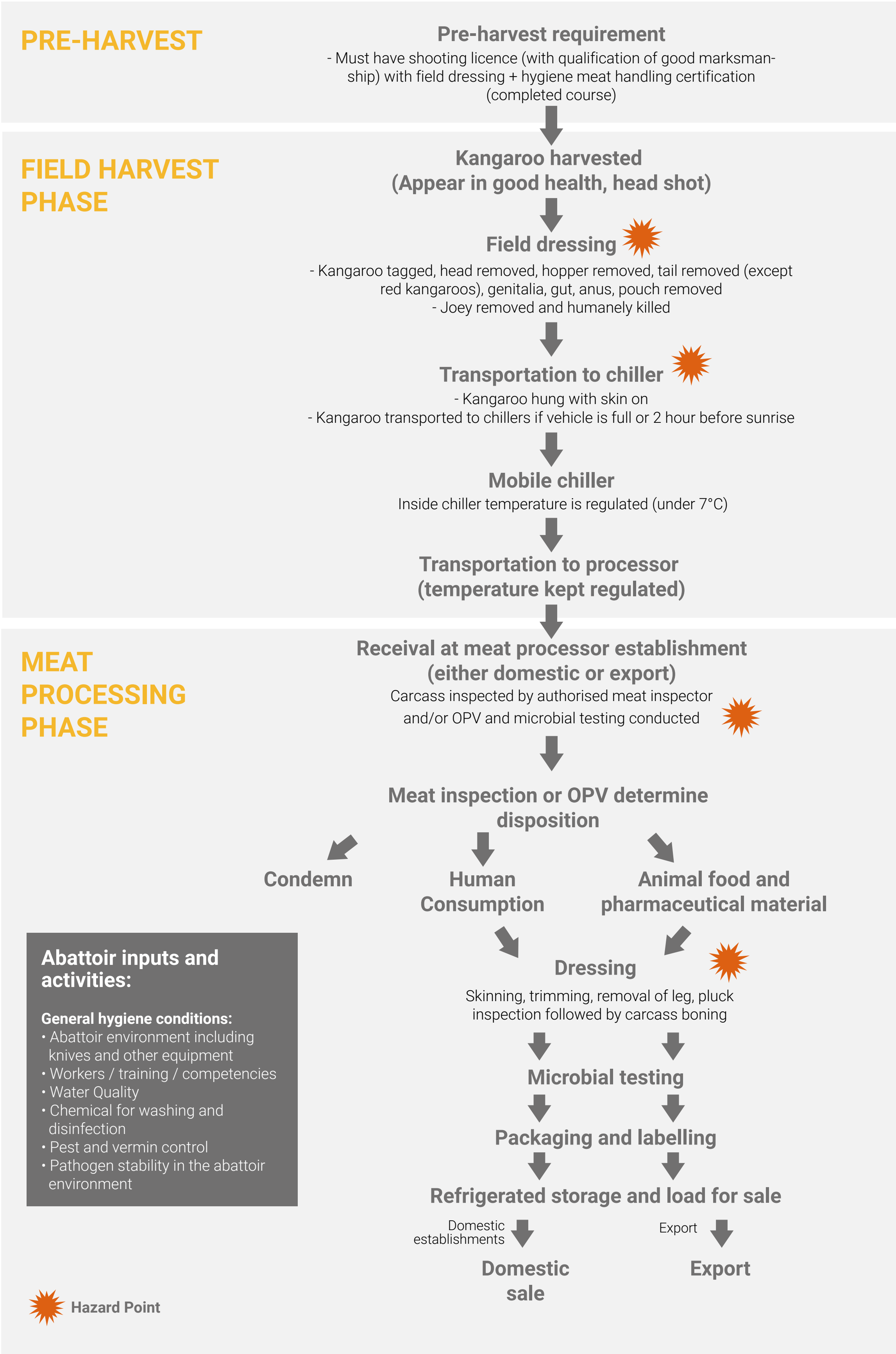
C.3 Packaging

Once kangaroo meat has been fully assessed and deemed suitable for processing, it is packaged and ready for commercial sale. More information on packaging and the data it requires can be found in the following sub-section on current traceability measures.

Raw Kangaroo meat inside a butcher's shop window in Melbourne Vic Australia

FIGURE 8

Ilustration of the kangaroo meat processing phases with reference to Food standards Australia New Zealand (2013). The labelled hazard points are where hazards have been identified and control points are in place



Male Eastern Grey Kangaroo

CURRENT TRACEABILITY MEASURES

The kangaroo meat industry has corresponding legal regulations and traceability requirements for each step in the supply chain, from population identification to harvest, processing, packaging, and sale (CSIRO 2006; CSIRO, 2008; Export Act 2020; AEMIS 2021; Export Control for Wild Game Meat Rules, 2021). These enable tracing back to the source of any potential contamination or disease transmission[108].

After harvesting, carcasses are tagged with the following information, at minimum: species harvested, date of harvest, time of harvest, location of harvest, and name of field harvester. This information is crucial for tracing the harvested kangaroo to its source.

Meat packaging requires information on the species harvested, the packing establishment, a refrigeration statement, the product in the package (which specific part or cut of meat is inside the package), a tracing system to identify individual production batch, and all raw material involved in processing. The tracing system to identify individual production batch enables identification of the field harvester, batch in which the kangaroo was processed, date of processing, total size of batch, name and address of the business that consigned the wild game meat, and date of consignment.

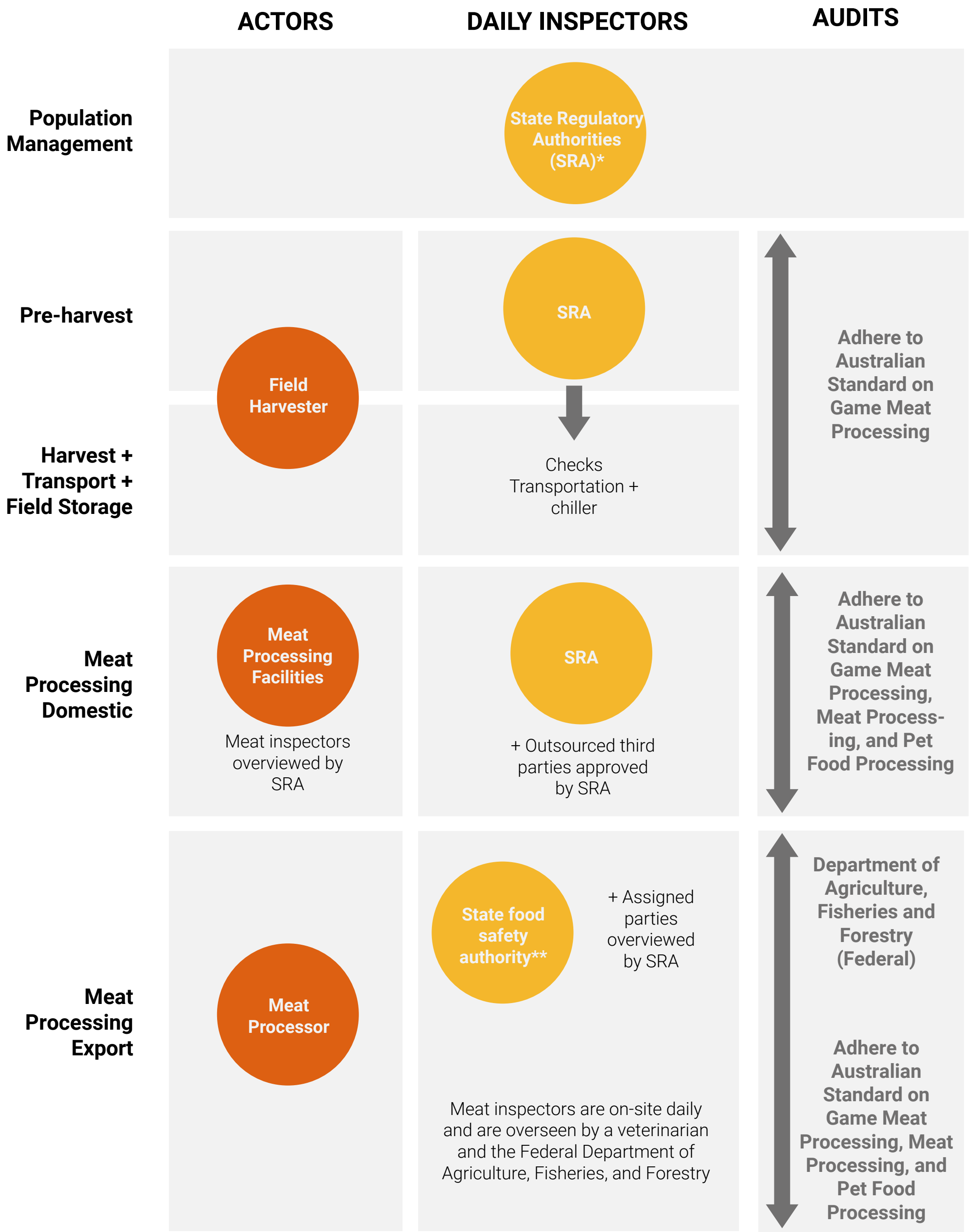
The current tracing system in kangaroo meat production still relies heavily on paper-based notes and information management by individual processors and businesses. The government regulation requires and audits that all parties have well-maintained logbooks or information management systems, but the industry has no standardised information systems. In 2021 the Australian government issued grants to develop better record keeping and data management systems for the industry. Tracing systems with scannable codes to capture all information from kangaroos' source harvesting to final processing are currently in development[109].

RESPONSIBLE STAKEHOLDERS AND REGULATIONS IN THE KANGAROO MEAT TRADE

Several stakeholders are involved in Australia's kangaroo meat trade. All export-oriented trade is regulated at the national (federal) level by the Department of Agriculture, Fisheries, and Forestry; however, in the field practice can be performed by State Regulatory Authorities (SRA). For domestic level establishments, production is regulated under State authority, while monitoring for HACCP compliance is regulated and inspected under the food safety authority of each State (Figure 9).

FIGURE 9

Stakeholders involved in the Australian kangaroo meat supply chain. NSW = New South Wales, QLD = Queensland, SA = South Australia, WA = Western Australia, EU = European Union, OIC = Office of International Coordination.



**QLD = Dept. od Environment and Heritag Protection, NSW= Office of Environment and Heritage, SA = Dept for Environment and Water, WA = Dept od Biodiversity, Conservation and Attraction*

***QLD = Safefood Queensland, NSW = NSW Food Authority, SA = Biosecurity SA Food Safety Program (PIRSA), WA = Department of Biodiversity, Conservation and Attractions*

Butchers at a market in Melbourne, Australia.

LESSONS FROM THE KANGAROO MEAT INDUSTRY AND INSIGHTS TO OPTIMISE THE SUPPLY CHAIN FOR A SAFE, SUSTAINABLE, AND LEGAL SUPPLY

Regulations for Australia's kangaroo meat industry (and its wild meat industry more broadly) are continuously updated, and inspections and audits are regularly performed to monitor product quality and hygiene. If standards are not met, sanctions are applied to the relevant stakeholders. Although the industry relies on wild harvesting of animals, from the processing stage onward, the steps and standards are equivalent to those used for meat from domestic livestock. The industry has been approved for import into the EU, known for its high meat quality standards[110, 111]. The industry has responded to issues by providing training initiatives and revising regulations (which included public, industry and stakeholder consultations) to improve management. The industry continues to evolve by implementing advanced measures such as the use of x-ray machines, chiller data loggers, and developing a digital meat tracing system.

There remain several areas for improvement for the kangaroo meat industry to address. Domestic markets rely on State authorities to regulate practice, with differing regulations and standards among States (though equivalent outcomes need to be met under the national Food Standards Code[112]). Oversight of field harvest practice is limited, as is data for these audits and inspections. Audits, if present, are mostly done near chillers and not in the field[113]. The kangaroo industry is also under constant scrutiny due to harvesting one of Australia's most iconic animals[114]. Although the commercial industry is highly regulated, monitored, and has high food safety and animal welfare standards[115, 116], there still remain challenges to communicate this to the public. The kangaroo industry may provide a useful benchmark for pilot projects to adapt HACCP practices for wild meat disease risk management in other countries.

The main barriers to adapting Australia's kangaroo meat industry HACCP standards in other parts of the world are a) the resources required to implement such rigorous systems and b) variation of food safety standards among nations. A stricter standard implies increased costs of implementation, which in turn may create cost barriers to participation. More research should be conducted to assess which Critical Control Points in the kangaroo industry can be adapted to other regions, particularly field harvesting and meat processing points to minimise the risk of contamination.

SOUTH AFRICA'S OSTRICH MEAT INDUSTRY

CONTEXT OF SOUTH AFRICA'S OSTRICH MEAT TRADE

This case study details the biggest challenge to ostrich producers and importers of ostrich meat: avian influenza (AI). Evolving knowledge and regulatory adaptation have culminated in a situation in which ostrich farmers now work with authorities to quarantine, rather than cull, farms infected with outbreaks of AI, reduce the spread of AI from natural reservoirs (waterfowl) on their properties, and subject birds to intensive pre-movement and pre-slaughter testing for the disease.

South Africa's ostrich industry is represented mainly by the South African black-necked ostrich (*Struthio camelus var. domesticus*), which is a crossbreed between a wild Barbary ostrich (*Struthio camelus camelus*) and a Southern ostrich (*Struthio camelus australis*). Farmers have been engaged in ostrich farming, producing meat, feathers, leather, and skins in South Africa since 1820. In 2019 South Africa held more than 60% of the global ostrich meat supply[117], but due to socio-economic factors (e.g., the global financial crisis) and outbreaks of AI, the number of ostrich farms in South Africa has been decreasing since 2004, when there were some 740 ostrich farms in the country[118]. In 2017 South Africa had an estimated 588 registered ostrich export farms, which supplied five European Union-approved export abattoirs[119].

Approximately 160,000 birds are slaughtered annually nationwide[120]. Each slaughtered ostrich produces roughly 15-17 kilograms of prime meat cuts, and approximately 80% of all meat produced is exported to the European Union (mainly the Netherlands, France, Germany, and Belgium)[121].

The South African ostrich industry is overwhelmingly governed towards an export market, not only in the export of meat products but also feathers, leather, and associated products. The industry has produced more ostrich meat for export than for the domestic market every year since 2006, making it self-sufficient and export-oriented[122]. For this reason, this report focuses on the export market component (primarily of meat) and the associated legislative controls governing its production in South Africa.

OSTRICH SUPPLY CHAIN'S HAZARDS AND HISTORY OF DISEASE OUTBREAKS

The main diseases that have affected the ostrich industry have been AI, belonging to both low-pathogenic (LPAI) and highly pathogenic (HPAI) subtypes, as well as Newcastle disease (an avian paramyxovirus) and the viral Crimean-Congo haemorrhagic fever[123,124,125,126]. This case study focuses on AI, as ostriches in South African captive production systems are vaccinated against Newcastle disease, and the incidence of Crimean-Congo haemorrhagic fever in flocks is rare.

Although transmission of AI from ostriches to humans has not been detected, the risk of severe disease in humans due to AI is considered significant enough to be of concern[127]. Globally, there were 863 confirmed cases of AI in humans between January 2003 and February 2022. More than half of those cases in humans were fatal[128]. The European Centre for Disease Prevention and Control considers AI strains to be of concern due to their ability to generate mutations within the genome that enable mammal adaptation, or through reassortment, the exchange of genome segments between different viral subtypes from different species. These characteristics could lead to new AI strains transmissible to and among humans[129]. Specifically, there is increased zoonotic potential of AI following replication in ostriches due to the ability of the virus to select for mammalian-adapted PB2 mutations when it replicates in ostriches[130,131]. The South African ostrich industry has experienced several AI outbreaks since 2004. Most notable were the H5N2 HPAI outbreaks of 2004, which were the most devastating as the industry in the Eastern Cape was decimated when disease control measures at the time destroyed 10,000 birds. This was followed by another outbreak in 2006; a large H5N2 HPAI outbreak in 2011, which affected 42 farms; H5N2 HPAI and H7N1 LPAI in 2012; H7N7 LPAI in 2013; H5N2 LPAI in 2014; and H5N8 HPAI in 2017[132,133, 134,135]. The H5 and H7 strains are the most important potential zoonotic strains based on global case numbers and case fatality rates in humans[136].

STEPS IN THE OSTRICH MEAT SUPPLY CHAIN WITH CORRESPONDING HAZARDS AND CCPS

Expert elicitation (n=5 industry experts) and a review of the literature revealed that the Critical Control Points (Figure 10) for AI in the ostrich production chain are located at three key points in the lifetime of an ostrich:

1.The potential movement of young birds from hatcheries to a rearing farm (location A, with the associated movement event);
2.The rearing farm itself (locations B1 and B2), where birds between one day old and 12-14 months of age are roaming over larger land areas. This is the point in the supply chain where ostriches may come into contact with wild birds, usually waterfowl like ducks and geese, as well as ibis species[137,138]. The interaction between wild birds and ostriches at this point makes it the riskiest time in the ostriches' lives for AI transmission[139], as these wild birds are an AI reservoir and may pass the pathogen to ostriches [140 141];
3.The final point in the production chain, although less likely to create an issue, is when ostriches are moved from rearing farms to the slaughterhouse (locations C and D[142]). The primary reason for the lower risk at point location A (breeding farm, commonly referred to as a hatchery) is that the rearing of young birds from one day old to three months of age is very intensive. There is a high density of farmworkers moving inside chick houses, and these houses themselves are intensive (higher density of birds over a smaller surface area). The same is true for rearing farms with younger birds (Figure 10, B1). This movement of humans around the young birds scares away wild birds, and there are minimal opportunities for waterfowl to approach water and feed troughs which represent potential disease reservoirs in the transmission chain[143].

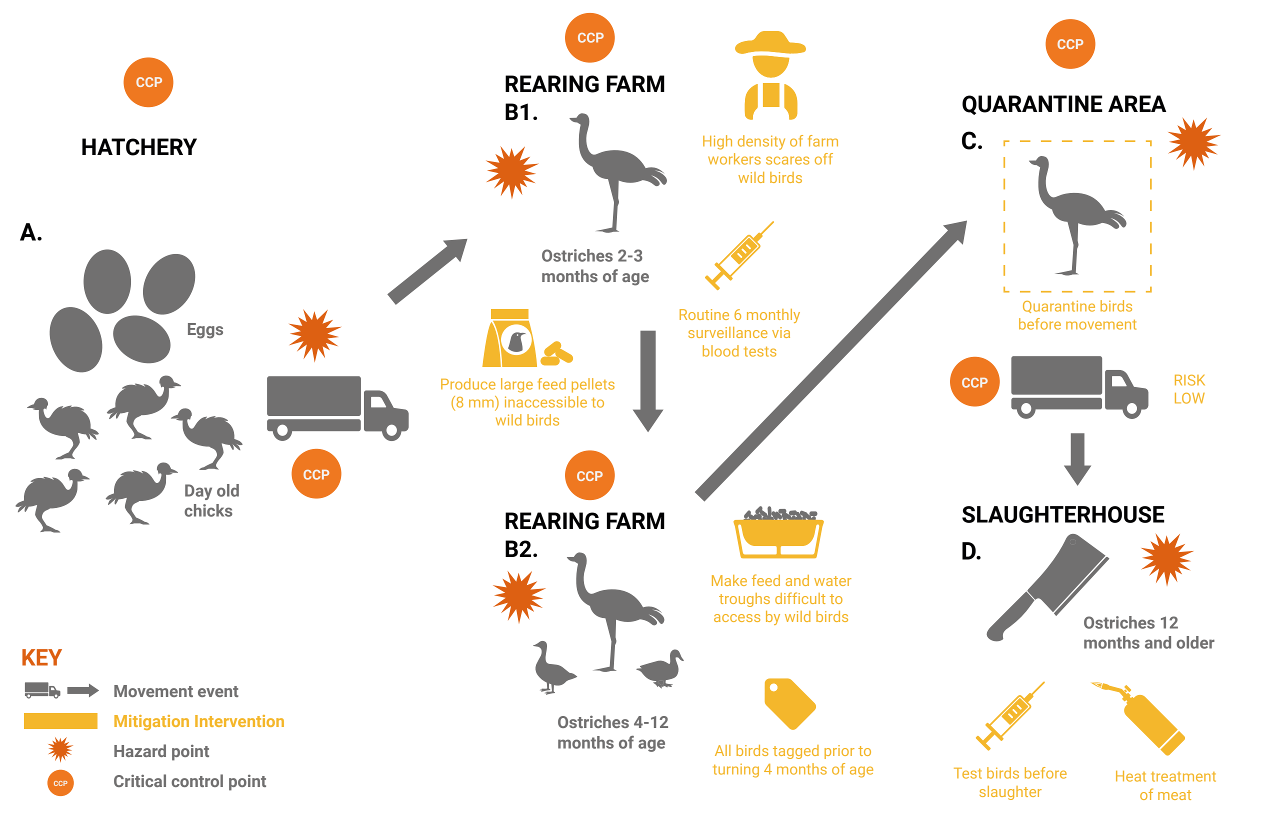
All industry experts in the elicitation process, as well as key literature, suggested that point B2 (Figure 10) is the most critical point where disease spread is likely to be highest. This is owed to less human interaction, and waterfowl can approach water and feed troughs without fear of disturbance, potentially accessing and contaminating both the ostriches' water and food. Coprophagia (the act of an animal consuming faecal matter) is also a problem as ostriches sometimes ingest waterfowl faeces[144 145]. The movement of ostriches between farms may decrease the resilience of the ostrich industry to AI outbreaks[146]. Bird movements between farms aggravate transmission potential and increase the potential that an infected bird arrives on another farm before detection of AI (lessons learned from the 2011 H5N2 outbreak). At locations C and D (Figure 10), the risk is arguably at its lowest point for four main reasons:

1.Ostriches are tested for AI using a blood test
2.They are quarantined for at least 14 days before moving to the slaughterhouse
3.Once at the slaughterhouse, they are subjected to both ante and post-mortem examinations by local veterinarians[147], and
4.Heat treatment of meat further reduces any minimal chance of AI being present inside the meat and jumping to a human host[148,149].

FIGURE 10

The mitigation measures currently being taken at the critical control points along South Africa's ostrich production chain (coloured yellow). These are implemented by both farmers and government authorities. Note that these are precautionary measures – there are a series of strict veterinary controls taken if a bird tests positive for AI (highlighted in the critical legislation section in Annex I). The most critical control point is at location B2. These birds are the most susceptible to contact with wild birds, which act as AI reservoirs. Each movement of birds between locations also represents a hazard point for transmission, as this is where birds experience the highest levels of stress (not only because of a change in environmental conditions but also potential changes in feed). Testing before slaughter and heat treatment of meat are the most important late-stage mitigation measures along the ostrich production chain in South Africa. CCP refers to critical control point.

Mitigating Measures to Stem the Outbreak of Avian Influenza at Critical Control Points Along the Ostrich Production Chain



Source: Personal Communication with Dr Adriaan Olivier, Joey Potgieter, Peter Coetzee and Anel Engelbrecht; Mather and Marshall (2011)

CURRENT TRACEABILITY MEASURES

Each ostrich under four months of age is tagged and vaccinated (for Newcastle disease) before any movement to a raising farm[150 151]. Newcastle disease vaccinations are mandatory, and certifications must accompany birds before their slaughter. The AI status of the farm where birds originated must also be presented when birds are slaughtered.

All birds must be tagged with a unique identification number which allows the ostrich to be traced to the farm of origin. Birds must come from registered farms. These farms should have been registered for at least six months prior to the slaughtering event, and the birds themselves must have lived on a registered farm for at least three months prior to slaughter. Pre-movement testing is mandatory, as is a permit, and movement can only occur to another registered farm. Slaughtering can only take place from registered farms.

RESPONSIBLE STAKEHOLDERS AND REGULATIONS IN THE OSTRICH MEAT TRADE

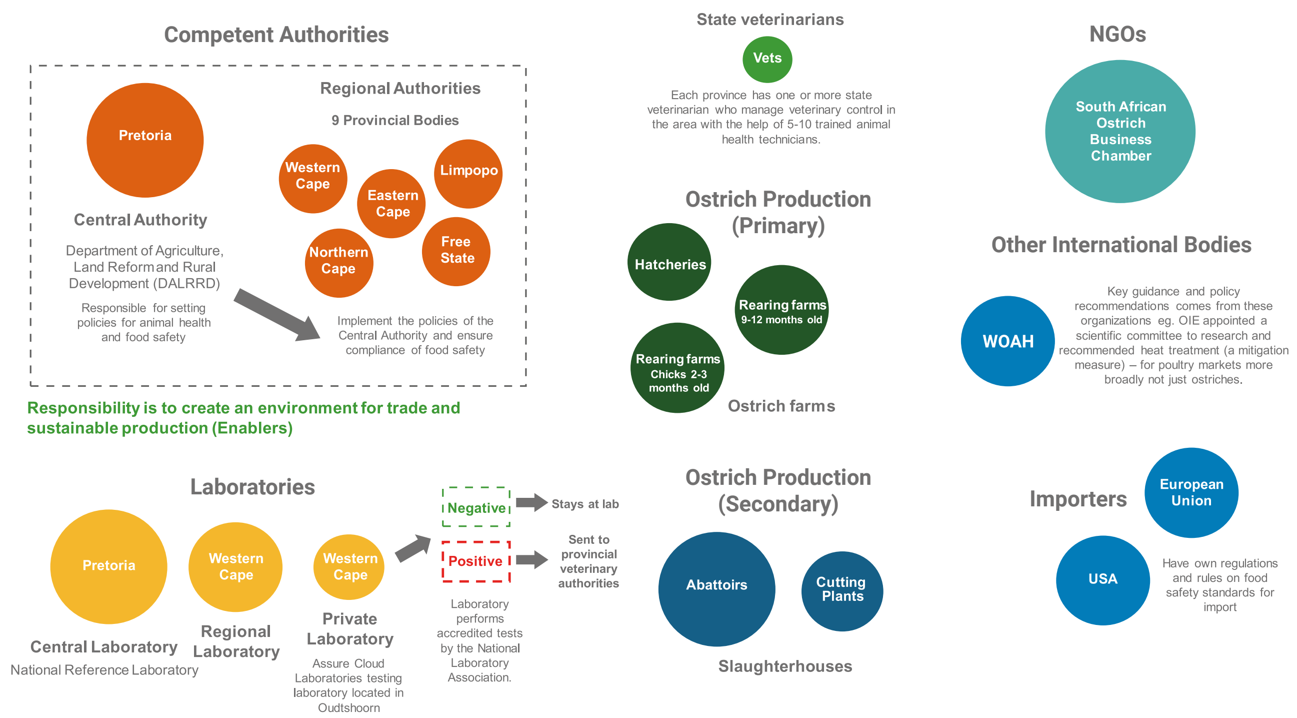
The ostrich production industry is heavily regulated by national authorities (the Department of Agriculture, Land Reform and Rural Development (DALRRD)) and regional authorities (one for each of South Africa's nine provinces). These are illustrated in Figure 11, and they work in collaboration with both primary ostrich producers and the associated secondary producers (abattoirs). International import regulators such as the EU also provide a set of guidelines to both producers and these authorities on meat and production standards, which are periodically audited in person, as led by the Directorate-General for Health and Food Safety of the European Commission in 2007[152] and 2016[153].

In terms of the evolution of ostrich production, governing protocols are issued by South Africa's Department of Agriculture, Forestry and Fisheries. One of South Africa's first pieces of legislation to support HACCP-based management was the 1984 Animal Diseases Act (Act 34 of 1984). This was augmented with production standards and rules in the Veterinary Procedural Notice (VPN) for the ostrich industry (Standard for the Requirements, Registration, Maintenance of Registration and Official Control of Ostrich Compartments in South Africa). This document was first drafted in September 2006 and supplemented an existing government gazette, No. R29155 Government Notice No. R.864. The VPN has undergone several revisions, most recently Revision 6.0 in 2012 (see Annex I for more details on this legislation).

Due to a lack of resources at the national/central and regional laboratories, the African Ostrich Business Chamber (a national representative body for ostrich farmers) has worked to establish a private laboratory, Assure Cloud of the National Occupational Safety Association (NOSA). This lab has become accredited by DALRRD and a national accreditation body as well as the central and regional authorities. It works to provide the most rapid surveillance system for AI nationally. Other professional and scientific organisations such as the WOAH work to provide authorities, producers and importers with scientific guidance and recommendations on food safety (e.g., WOAH designed and recommended heat treatment for poultry industries broadly, not just for ostriches[154]).

FIGURE 11

Key stakeholders and actors in the South African ostrich production market. Source: Adriaan Olivier, pers comm, 2021.



Assorted processed meat products at a market in France

FRANCE'S VENISON TRADE

CONTEXT OF FRANCE'S VENISON TRADE

The use of wild meat is deeply rooted in France's socio-cultural heritage, and for many centuries wild meat was the main source of protein in France. Today, venison continues to be a popular dish during holidays and special occasions, and is eaten as a luxury item. As many people reconsider their consumption preferences and prioritise local produce and traditional dishes, venison is seen as a healthier, more sustainable and environmentally friendly alternative to conventional meat sources from domestic animals[155].

In this report, the definition of venison covers a range of meat derived from cervids (scientific and French names in parentheses): Red deer (*Cervus elaphus*, le cerf), European fallow deer (*Dama dama*, le daim), roe deer (*Capreolus capreolus*, le chevreuil), and sika deer (*Cervus nippon*, le cerf sika). Historically, venison was harvested from the wild by hunting these animals, but with increased demand and changing consumer preferences, the French venison market is beginning to expand its sources to farming and ranching operations. The main products are meat and meat sub-products (*terrine*, *pâtés*, *saucisson* or *saucisses*). Most venison is used domestically (i.e., by hunters and their immediate circles).

Over the past decade, the demand for venison products has increased in France, though it continues to have a relatively marginal role in overall meat consumption (less than 0.2% in the European Union and less than 6.5% in France)[156]. Approximately 90% of all contemporary wild meat in the French market is imported[157]. In 2020, France was the sixth most significant global exporter of venison and the seventh most significant global importer[158].

VENISON TRADE'S HAZARDS AND HISTORY OF DISEASE OUTBREAKS

Like any other food system, the venison trade has inherent risks associated with the different processes along the supply chain. The health risks linked to the venison trade can be classified as physical, chemical, and biological. Humans are exposed, directly or indirectly, to different hazards throughout the supply chain (i.e., hunting, handling and field inspection, transport, processing, storage, distribution, retail, preparation, and consumption). Several zoonotic diseases have been associated with deer: Q fever, chlamydiosis, leptospirosis, campylobacteriosis, salmonellosis, *E. coli*, cryptosporidiosis, giardiasis, tuberculosis, brucellosis, chronic wasting disease (although there is no current evidence of zoonotic transmission, it is strongly recommended to avoid consuming meat from diseased animals), deer *Parapoxvirus*, Echinococcosis, Ehrlichiosis (tick-borne disease), Lyme disease, Sarcoptic mange, Tularemia, Crimean Congo haemorrhagic fever[159,160,161,162,163,164]. However, association with these diseases does not necessarily mean the individuals or population will carry them. The health risk associated with wild deer is lower than game birds, wild ducks, and lagomorphs (e.g., rabbits and hares)[165], and meat contamination with *Salmonella* or *E. coli*, although reported, seems to be rare[166].
Current consumer preferences favour more extensive and open models for livestock production. In contrast, the increase in demand for wild meat has led to the intensification of the production model (from a primarily wild-caught harvest to a more intensive farming model)[167]. As systems and practices adjust, this will likely modify current disease transmission dynamics, creating new interactions between hosts, pathogens, and the environment.

STEPS IN THE VENISON SUPPLY CHAIN WITH CORRESPONDING HAZARDS AND CCPS

There are two sources of venison: **1)** from breeding (or farming) facilities and **2)** wild-caught (hunted). In 2015, France had 400–500 red deer and 600 European fallow deer farms, according to figures from the National Union of Wild Meat Producers (*Syndicat national des producteurs de gibier de chasse*, SNPGC). Only certified providers who either hold a valid hunting licence or are an official wild animal farming establishment (also known as a primary producer or supplier) can enter the commercial supply chain. The French supply chain (also called a circuit) is classified according to the type of use (e.g., personal or commercial use) and the number of intermediaries between the source and the consumer (i.e., direct or indirect). There are three main classifications according to the general characteristics of the supply chain, see Figure 12:

- Short-direct
- Short-professional
- Long circuit

Each of the circuits goes through different stages before reaching the consumer. The stages are organised as follows:

1. Source (primary producer or supplier):
  - **a.** Hunting
  - **b.** Farmed
  - **c.** Import

2. On-site processing
3. Collection hub
4. Processing
5. Wholesale
6. Retail
7. Consumer

The different circumstances in which venison is sourced, used, and sold result in variations in the number and type of critical control points and compulsory procedures involved. The venison products are sourced from farms, wild harvest (hunting), or imports. Animals sourced from farms are processed on-site, followed by an on-site veterinary inspection. Before reaching the consumer or an export distributor, the carcass can then go to a processing facility, such as a certified abattoir, a wholesaler, or retailer. These different Critical Control Points and mandatory procedures along the supply chain are:

- **Pre-harvest stage**

Each year, the French Biodiversity Agency, local authorities, and local and national hunting associations develop a hunting plan to allocate the yearly quota of animals harvested in each geographical department[168]. Once the allocation is set, individual tags are sent to each hunting association, which then sells the tags to hunters. For example, the cost to hunt a male red deer is 171€[169]. These individual tags provide the basis for the traceability system.

- **Wild-harvest stage**

For the short-direct supply chain (i.e., the hunter and their inner circle), only the identification of the animal is mandatory[170]. In contrast, post-mortem sanitary inspection and traceability measures are not required, merely recommended, because the product will not enter a commercial supply chain (it is compulsory to produce a specimen form for official records, see link in endnote[171] for an example). According to French legislation, the hunter (or primary supplier) is fully responsible for ensuring the product's safety in this case, and civil liability legislation applies. It is estimated that 92% of all venison is consumed domestically by the hunter and their close circle, 5% goes to the food industry, 2% is offered to charity, and 1% is lost for various reasons[172].

Both short (direct and professional) and long circuits begin when a certified person (not necessarily a hunter) conducts the initial sanitary inspection. This inspection assesses the condition of the animal and its organs and provides official documentation for the carcass to enter the commercial supply chain as a product safe for human consumption. The commercial supply chain is called a *short* supply chain when it is limited to 80 km from the hunting location. It also usually involves one certified intermediary (i.e., processing, restaurants, or retailer), and it is limited to the total number of animals hunted during the session (i.e., one day). The long commercial circuit has no distance restriction, is not limited in quantity, and may include multiple intermediaries (Figure 12).

- **Processing and retail**

In the short-direct supply chain, the hunter can perform processing, i.e., skinning and cutting. It is possible to sell products or by-products to approved retailers or directly to consumers. However, if a sale is involved, then a post-mortem examination of the carcass is mandatory, as is the use of a Wild Meat Support Sheet [173] [174]. The Wild Meat Support Sheet gathers information for traceability, and copies of it must be stored for five years by the examiner, hunter, and recipient of the meat. For non-sale use, these measures are recommended but not mandatory.

In the short-professional supply chain and the long circuit, the primary supplier sells the carcass 'in-fur' to an abattoir or certified processing and collection hub to process and transform the carcass into meat cuts and sub-products. For the long circuit, the product will then continue to a second intermediary, either a wholesaler or a secondary processor. Next, the products and sub-products could go to another intermediary (a retailer who sells or transforms) before reaching the final consumer. In addition to the initial sanitary inspection, the long commercial supply chain has additional control points performed by certified veterinarians.

CURRENT TRACEABILITY MEASURES

A key aspect of the venison trade in France is the importance of the initial sanitary inspection and general traceability practices. The initial sanitary inspection is performed on-site by a certified person. The procedure for the initial inspection of the carcass was co-developed by the French Veterinary Associations and the National Hunting Federation and is performed by veterinarians who have been certified at the geographical department level. The objective is to certify the traceability of the animal and carry out an initial, on-site inspection of the carcass. If the carcass goes into the commercial supply chain, certified veterinarians perform additional inspections before the processing stage. The carcass must have an individual bracelet tag with specific information, including the date, location, type of animal, and estimated age (see Figure 13). These bracelets are assigned to each hunting association according to estimated population numbers defined in the species' hunting plan.

FIGURE 12

A simplified representation of three main venison supply chains: 1) Short-Direct, 2) Short-Professional, and 3) Long circuit. The hazard identification is based on direct and indirect transmission (e.g., fomites, cross-contamination) of biological agents (e.g., viruses, bacteria, and macroparasites). Each stage of the supply chain carries associated health risks that can be lowered by implementing control measures such as the use of protective gear, appropriate use and sanitation of tools and materials, veterinary controls, and others. Cold storage prior to the collection hub is mandatory for the Long circuit, and strongly recommended for the Short-Professional and Short-Direct circuits; beyond this point, cold storage is expected for all circuits. Sources: See endnotes[175],[176],[177].

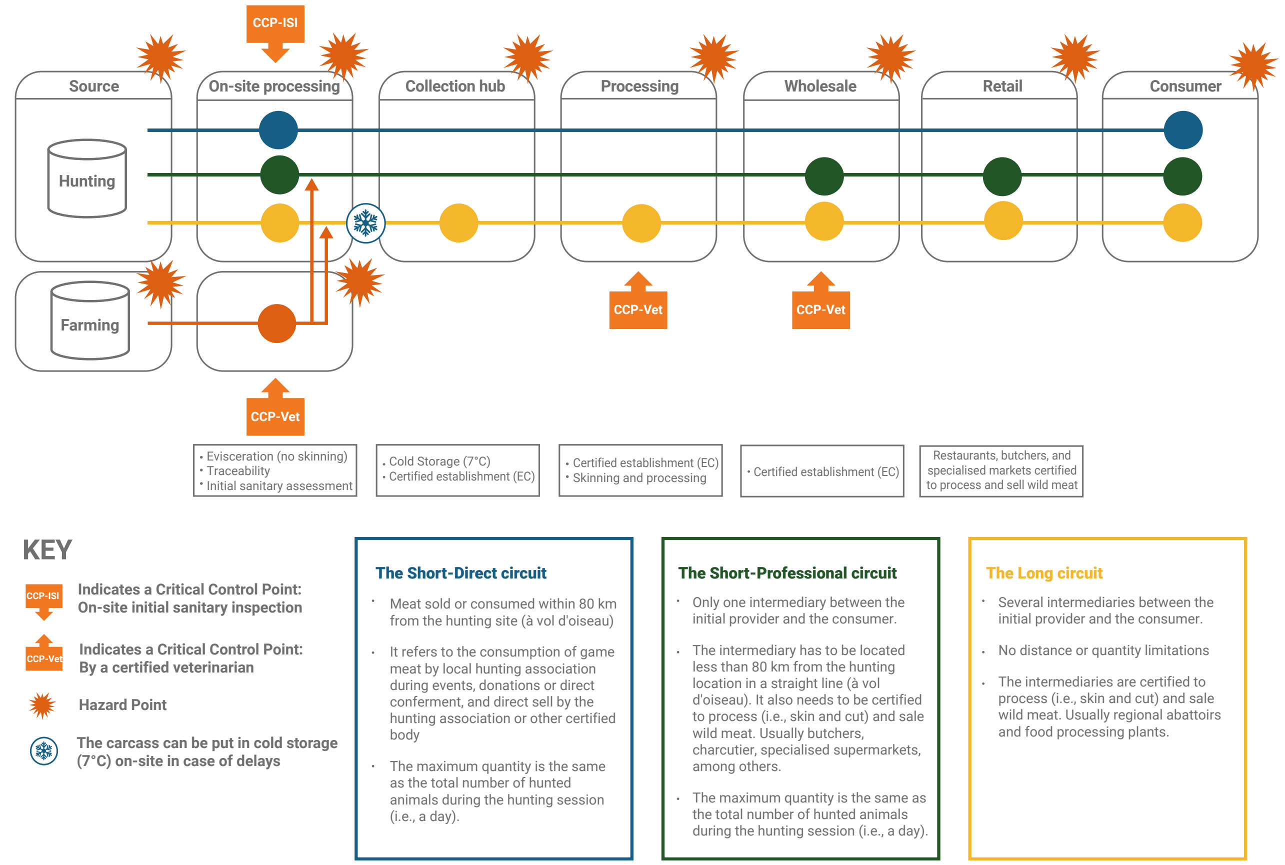
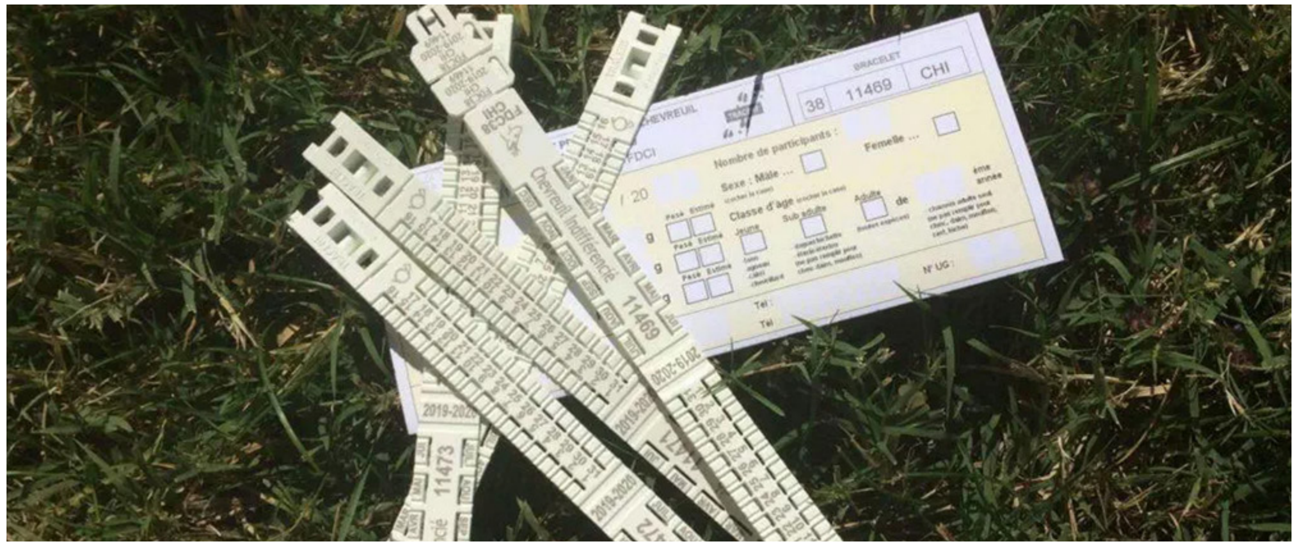


FIGURE 13

Example of individual tagging bracelet and specimen form to control the number of animals hunted each season (2019-2020 season). Source: Fédération Nationale des Chasseurs, France



RESPONSIBLE STAKEHOLDERS AND REGULATIONS IN THE VENISON TRADE

The venison industry in France involves multiple actors simultaneously managing and supervising different aspects of the industry through multiple levels of governance[178]. Figure 14 provides a general representation of the multiple stakeholders and at which governmental level they act (1 through 8, from international to local organisations). Following a top-down approach:

- International organisations (1) like WHO, WOAH, and FAO provide general, non-binding guidelines
- At the European Union level (2), the commissions and agencies provide overarching regulations that every member state must comply with
- At the national level (3), the ministries and national organisations synthesise, organise, and design laws and regulations that, while aligned with EU Regulations (CE), adapt to the national conditions and requirements;
- At the Department level (4), regulations and laws are implemented by the interconnected actions of multiple private, public, and non-governmental stakeholders (e.g., the conception of hunting plans);
- From 5–8 are the organisations and groups required to supply, transform, and use the venison product.

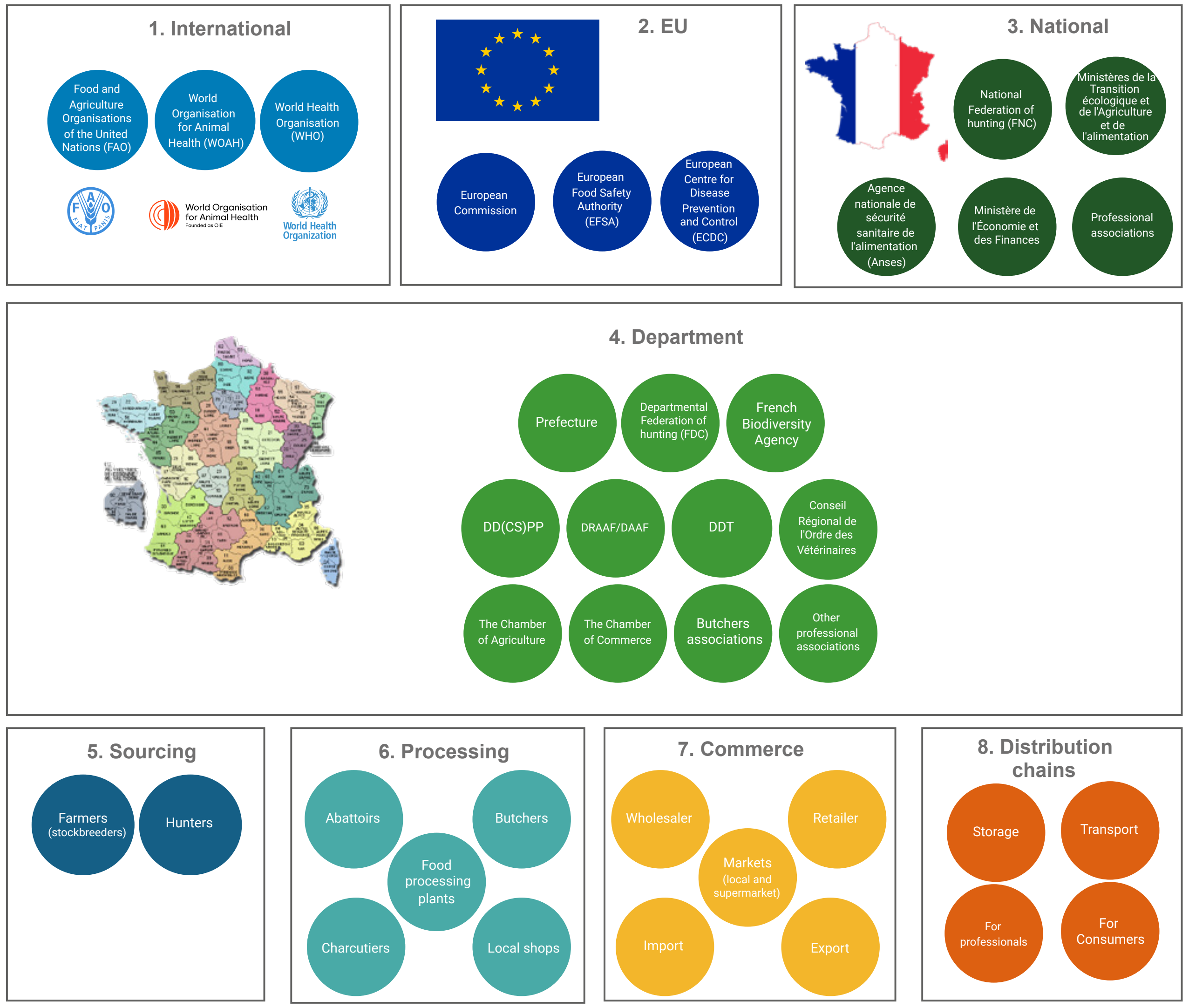
Multiple regulatory and legislative bodies apply at different levels or practices in the venison supply chain (see Figure 14). The European Commission (EC) regulations provide the general framework for specific legislation at national and subsequently local levels. The EC promotes a unified approach to all EU members and associated states and provides an outline for non-EU countries that wish to trade goods within the EU market. The seemingly complex regulatory system with its multiple legislative levels, diversity of actors, and international coordination, unifies practices across the supply chain, guaranteeing a safe product to consumers and facilitating trade among countries that have adopted these guidelines.

In France, venison has three sources or primary suppliers: imports, farmed, and hunted (wild-harvested) animals. The possession and captive breeding of wild animals is governed by Articles L. 413-2 and L. 413-3 of the Environmental Code and its implementation documents (Ministère de la Transition écologique, 2017). The objective is to complement European and International Legislation (e.g., CITES) to enhance the protection of wild species. Farming (or breeding) establishments (les établissements d'élevage) must comply with the Environmental Code and have the 'Certificate of Capacity' (le Certificat de Capacité) that shows the person responsible for the animals has the necessary competencies to hold that species in captivity. Farmers must also have the 'Operating License' (L'Autorisation d'ouverture de l'établissement). Large game from farms can be sent directly to abattoirs, slaughtered on-site, or introduced into hunting areas (or hunting enclosures, parc de chasse or un enclos cynégétique in French) pending authorisation by the Department's Prefect (Puy-de-Dôme, 2015). Animals from farms must follow the sanitary protocols developed by local authorities (Departmental Directorate for the Protection of Populations (DDPP) and official veterinary services). Additionally, all animals must be individually identified with tags.

EC Regulation No. 853/2004 lays out specific hygiene practices according to the animal category (e.g., livestock, wild meat, fish, honey, eggs, etc.) and requires ante-mortem inspections for all animals to be slaughtered in abattoirs. Once the carcass enters the commercial supply chain, it can only go to certified facilities (i.e., collection, primary and secondary transformation) before going to a wholesaler or retailer. Products cannot be introduced into the commercial market unless they have gone through an official veterinary inspection. All facilities (i.e., collection, transformation, transport, and commerce) must be registered, and a list must be available and updated (Ministère de l'Agriculture et de l'Alimentation, 2021)

FIGURE 12

Key stakeholders in the venison supply chain in France



LESSONS FROM THE VENISON TRADE AND INSIGHTS FOR SAFE, SUSTAINABLE, AND LEGAL SUPPLY CHAINS

The French venison trade provides a good example of how animal products can be coordinated at multiple levels. Multiple stakeholders oversee and participate or collaborate in the French venison trade, from the European level through EC Regulations to national and local legislation. France's hunting associations play a critical role in managing wild deer populations via their model of sustainable use. The legislative framework and specific regulations, although numerous, clearly regulate specific components and practices of the supply chain. European legislation is also used internationally to regulate trade with EU members and as a general framework to define national trade and sanitary systems. The legislation's main objective is to ensure that products are safe for human consumption, but it has been expanded to regulate animal welfare, sustainability, and general environmental responsibility (e.g., waste disposal requirements, antimicrobial use, etc.). The sanitary control points, although minimal, place the responsibility on the primary supplier (the hunter or farmer) who wishes to sell their product via the commercial supply chain. As domestic consumption represents the main use of venison in France, strengthening sanitary requirements or developing effective frequent surveillance strategies should be a priority to minimise the risks of missing important sanitary information[179].

France's venison trade is also a helpful model in the search for context-specific approaches to mitigate disease risks among different forms of wild animal trade. Risk mitigation requirements and options for trade are determined based on the length of the supply chain (determined by the distance from the hunting site) and the chain's complexity (determined by the number of actors and intermediaries involved).

As consumer preferences evolve, production practices tend to change accordingly. A clear example of this effect is the change in wild animal management, which is moving towards more intensive farming models, whereas traditional livestock systems are moving towards more extensive models (e.g., free range chicken). These shifts in production practices will likely modify the current disease dynamics, creating new interfaces for disease transfer among animals and people. One of the leading consumer motivations for using wild meat is that it is 'free-range,' so consumer perceptions may change if systems move towards more intensive production.

Refrigerated meat at a processing factory

LESSONS FOR IMPROVING SUPPLY CHAIN MANAGEMENT AND TRACEABILITY

Many of the lessons learned from existing supply chain management and traceability examples are not taxa specific and thus carry value for enhancing the safety and sustainability of other forms of legal wild animal trade.

FOUNDATIONS FOR ENHANCING SUPPLY CHAIN SAFETY

Each wild animal trade system is underpinned by unique socioeconomic, cultural, and political factors. In China, for example, the establishment of wild animal farms was historically encouraged by the government as a means of poverty alleviation and rural development[180]. In the Republic of Congo and elsewhere in Central Africa, wild meat consumption is partly driven by its association with traditional culture[181]. Understanding such factors is essential to making positive participatory change in the system. To encourage stakeholders along the trade chain to shift their practices in a legal, safer, and more sustainable direction requires active consultation to ensure One Health principles (see Nomenclature section for an explanation of One Health) are understood, contextualised, and applied. Incentives for good practices such as disease reporting need to be applied just as consistently as deterrents for illegal practices.

Changes in wild animal trade systems may pose risks to public health without necessarily carrying conservation risks, the lens through which wild animal trade is more often viewed. South Africa's ostrich industry does not source animals from the wild and would not typically pose risks to ostrich conservation, but the risks of AI within the industry are an important concern for public health. When wild animal trade issues such as this are viewed through a public health lens, this can make the issues more relevant to government authorities and enable broader public resourcing to mitigate risks.

EXERCISING DUE DILIGENCE

Audits can be an important tool for assessing that a traceability system is operating as intended, but they are not a perfect solution. In developing countries and particularly in rural developing areas, there may be limited capacity for conducting regular inspections and audits[182]. Virtual audits have become more common over the course of the COVID-19 pandemic, but there is still a need to invest in local auditors with local expertise. This helps to improve efficiency and lower costs, and local auditors can be better equipped to spot inequalities in the supply chain, such as the exploitation of female workers[183].

Local inspectors and auditors can also work collaboratively with producers to build trust and gradually improve their production practices over time, recognising that immediate compliance may be impossible where resources are lacking[184]. In countries like Tanzania where regulations for legal wild animal trade are newly developed[185], established networks of livestock extension officers, livestock meat inspectors, and health officers[186]can help form the foundation of food safety monitoring for legal wild meat trade. Risk assessments and stakeholder engagement can be a better-integrated option for supply chain improvement than audits. Support from civil society and local pressure to improve supply chain standards are likewise important influences for change in supply chain practices[187]. This suggests the value of combining efforts to improve supply chain management and traceability with SBC interventions to build demand for legal products that are traceable and more sustainable and safe.

ECONOMIC CONSIDERATIONS FOR TRACEABILITY SYSTEMS

Capturing more detailed information in a traceability system raises the cost and effort of participation. Greater detail is not always necessary; to reduce cost and complexity, a system can trace groups of products or animals rather than individuals[188].
Costs of participation will need to be fairly distributed along the supply chain to ensure that all actors are involved equally. Small-scale producers can play a major role in the introduction, spread, and control of diseases, but these producers often do not participate in traceability programmes because, at their small scale, they are less affected by the economic incentives for compliance. Legal measures can help to deter such free riders, and an insurance scheme can help to account for the risky or fraudulent behaviours of certain actors along the chain[189]. For improved supply chain management and traceability measures to be economically viable, the costs of these measures will need to be internalised from the beginning. National public health systems are generally better developed and resourced than corresponding animal health systems. A One Health approach that involves public health authorities in these wild animal supply chain reforms can enable significantly greater resourcing for disease surveillance. Identifying links between animal diseases and human disease outbreaks creates greater relevance for animal health and moves limited government resources closer to the source of disease emergence and prevention.

In the event of a disease outbreak or other restrictions through which the government requires farmers to cull their animals, pay-outs must be fair and timely to incentivise reporting of any diseased animals. In Viet Nam's 2019 African Swine Fever outbreak, farmers were paid out at 80% of the market price for culling their pigs, but some farmers sold off their infected pigs rather than reporting to authorities[190].

Small-scale farmers have limited capacity for biosecurity measures compared to big farms, but big farms can have higher chances of infection. One solution to this issue relies on a less intense production model, which will require a broader reduction in consumption and demand for animal products[191].

BENEFITS OF PARTICIPATION IN TRACEABILITY SYSTEMS

Requirements for improved supply chain management and traceability need to be kept in proportion with the benefits that supply chain actors perceive they will gain by operating within the legal, traceable framework; otherwise, these requirements will not incentivise compliance. Several benefits that could serve as incentives include:

a) Meeting legal requirements;
b) Saving money by improving efficiency;
c) Better collaboration along the supply chain;
d) Improved reputation and consumer trust;
e) Greater market access[192].

Research has found that consumers may be willing to pay two to 10% more for products from companies that provide greater supply chain transparency[193]. Food safety is a major concern for developing markets like Viet Nam[194] and China[195], and research has found that most Chinese consumers are willing to pay a premium for products with better food safety along the supply chain[196]. Gaining access to international markets with stricter product standards, such as the EU, can also provide a business incentive for implementing traceability.

DEFINING 'SAFE' AND 'SUSTAINABLE'

'Safe' and 'sustainable' are both subjective criteria that societies and governments will need to define (and occasionally redefine) for themselves. Every system will have some residual level of risk, so the key is to establish what measures are needed to mitigate these risks to an acceptable level. Driving a car, for example, can be a very unsafe activity, but people accept the risks daily while focusing on risk mitigation efforts such as seat belts, airbags, and traffic laws.

As new wild animal trade situations emerge, real-time surveillance of wild animal and domestic animal health and pathogen emergence will be needed, led by appropriate levels of government, to enable regulations and restrictions to evolve accordingly. Not all countries have the necessary surveillance capacity for this, hence the importance of combining resources across public and animal health sectors and international collaboration on One Health. Emerging novel pathogens pose a greater risk for spread and pandemics than routine zoonoses that we have learned how to treat and should be prioritised for monitoring[197].

The disease risks of wild animal trade cannot be disassociated from livestock production risks; the two systems must be considered in tandem with regular assessment of their overlapping disease transmission roles. The intensification of industrial livestock production comes with significant disease risks, but societies have thus far chosen to accept and treat these risks, as with *Salmonella* in poultry[198]. For targeting zoonotic disease risks, in the food sector, the primary focus should be on farms and points of intensifying production (in both developed and developing countries, for both livestock and wild animals) and species mixing, rather than on local small-scale subsistence use at the community level.

Two men 'Transporting a blue duiker on a motorbike, East province, Cameroon.

GAPS AND OPPORTUNITIES

GAPS

In assessing the findings of this Review, several gaps in knowledge emerge that will require further investigation.

As noted in the Methodology and Limitations section, additional research is needed to explore how supply chain management and traceability interventions can help to improve the sustainability of wild animal trade systems and prevent illegal practices. More research is also needed to assess how improved supply chain management and traceability can be applied to trade in live wild animals kept as pets and used for scientific research or for display, and trade in wild animal-derived medicines.

To adopt or adapt best practices in supply chain management and traceability to new contexts, particularly in developing countries and less regulated trade chains, additional research will need to assess the costs of these practices and how these costs can best be distributed across the system. Funding needs and mechanisms will vary based on each context and supply chain. The funding needed for applying best practices will partially depend on the country's existing infrastructure for veterinary services, disease surveillance, and livestock regulations. Can the country expand such existing systems to wild animal trade, or are these systems already stretched thin? These infrastructural costs involve long-term development and are therefore difficult to quantify and compare between nations. In addition to the costs of improved supply chain management and traceability practices, what adaptations to these practices may be needed to accommodate for national differences in governance, legal compliance, and corruption risks?

In revisiting the three principal case studies for this Review, TRAFFIC asked who pays for these systems' controls and traceability measures? How have the costs been integrated into the systems to avoid overburdening any set of actors along the trade?

Looking deeper at the regulatory environments for each case study system, are these regulations and practices government-derived, or have businesses and stakeholders designed them? If the latter, are there any pro-industry biases? Are the requirements in these systems strictly implemented in practice or just on paper? Do stakeholders seek to avoid the requirements, how often does this happen, and what sanctions are applied?

Also relevant to the case studies, how has monitoring and evaluation been used, or how does it need to be better employed? How have improvements to these systems' supply chain management and traceability been monitored, and how has this information been used to continuously build on these improvements? Have reforms and new regulations succeeded in reducing pathogen presence along the trade chain and in the final product? Are there feedback loops that enable adaptive management of these systems? An example of a plan to enhance food safety in Australia's kangaroo meat industry can be found in this endnote[199]. Further exploration of these questions can support the modelling of similar trade management systems in other contexts.

OPPORTUNITIES

Opportunities to put the learnings of this Review into practice are discussed in respect to:

1. An international enabling environment with the potential to support a broad range of activities in this field; and
2. Specific opportunities for TRAFFIC's Wildlife TRAPS project to pilot new wild animal trade chain interventions.

Opportunities for others to engage with the issues covered in this Review, both independently and in collaboration with TRAFFIC, are covered in the Recommendations section.

Since the outbreak of the COVID-19 pandemic, several intergovernmental platforms have pushed for new efforts to make wild animal trade safer. One such proposal was to amend CITES to include an appendix limiting international and domestic trade in species deemed to carry a high risk of zoonotic disease transmission. Historically, CITES appendices have focused on listing species whose conservation is at risk due to international trade, but without regard to zoonotic disease risks[200]. Research by the United Nations Environment Programme's World Conservation Monitoring Centre and the United Kingdom government's Joint Nature Conservation Committee found that between 2009 and 2018, 800,000 reported CITES trade transactions involved a taxonomic family associated with one or more zoonotic diseases[201]. In April 2021, the CITES Standing Committee established a working group to consider what role CITES could play in reducing risks of future zoonotic disease emergence via wild animal trade. The working group on the *Role of CITES in Reducing Risk of Future Zoonotic Disease Emergence Associated with International Wildlife Trade* reported its findings to the 74th Meeting of the CITES Standing Committee in March 2022[202]. The Standing Committee approved several draft Decisions to be presented to the 19th Conference of the Parties to CITES, scheduled for November 2022[203]. Before the pandemic, CITES established a working group on traceability in 2016[204]; one opportunity may be to link these efforts, using traceability to ensure that the trade in CITES-listed species remains safe from zoonotic disease risks.

An initial rush to find new solutions and create alliances early in the pandemic is now solidifying into better-organised efforts for exploring interdisciplinary solutions to potential zoonotic disease transmission risks from wild animal trade. Another platform for international collaboration is the WOAH. In March 2021, the

WOAH released its Wildlife Health Framework for improved disease risk management at the human-animal-ecosystem interface, in which the safety and sustainability of legal wild animal trade are essential[205]. As noted in the case studies, the WOAH has previously played an important role in harmonising health and safety standards for animal trades globally. Since mid-2021, WOAH has convened an Ad Hoc group to work on *Draft Guidelines for Reducing the Risk of Disease Spillover Events at Markets Selling Wildlife and along the Wildlife Supply Chain.* The outputs of this expert consultation process will aim to provide practical science-based guidance to authorities to improve biosecurity and sanitary measures, reduce risks of disease transmission, improve animal health and welfare, and conserve biodiversity through regulatory principles. For the Wildlife TRAPS Project to pilot interventions to improve the safety and sustainability of legal wild animal trade chains, potential project sites include Cameroon, China, Tanzania, and Viet Nam. The two most promising opportunities to date are in Tanzania and Viet Nam.

In Tanzania, new national government regulations have allowed legal trade in wild meat through government-approved butcheries since late 2020[206]. The number of licensed butcheries has grown rapidly over the past year, from 34 operating in November 2021 to 74 operating in February 2022, and additional applications for licenses are expected[207]. The Tanzania Wildlife Management Authority (TAWA) has limited experience in zoonotic disease surveillance and spillover preparedness. Before establishing the 2020 Wildlife Conservation (Game Meat Selling) Regulations, there were no control systems or traceability mechanisms in place to monitor zoonotic pathogens across Tanzania's wild meat trade. There is a need for improved supply chain management and traceability to verify that wild meat sourcing is legal and sustainable and that processing minimises any risks of zoonotic pathogen transmission.

In Viet Nam, a 2021 survey by GlobeScan and WWF showed that wild animal product purchasing, both at physical markets and online, remained more widespread than in neighbouring countries throughout the first year of the COVID-19 pandemic[208]. Wild meat consumed in Viet Nam is often sourced from the country's wild animal farms, which may present additional risks of zoonotic disease emergence and amplification[209] due to poor husbandry practices, mixing of different species, introduction of wild-caught animals, and insufficient government monitoring[210 211]. Species commonly farmed in Viet Nam with potential zoonotic disease risk include civets, primates, porcupines and wild boar[212]. TRAFFIC has been mapping Viet Nam's trade in wild animals consumed for meat and as informal traditional medicines, and is consulting with animal and public health experts to assess which points in the trade are most important to target in reducing risks of zoonotic disease transmission. Simultaneously, TRAFFIC is part of a consortium of NGOs, IGOs, embassies and development agencies working with the government of Viet Nam's One Health Partnership via a Technical Working Group on Wildlife and Pandemic Prevention. This collaboration with Viet Nam's Ministry of Health, Ministry of Agriculture and Rural Development, and Ministry of the Environment and Natural Resources creates a valuable enabling environment for developing solutions to improve management and strengthen the biosecurity of legal wild animal trade chains in the country.

Complementary to these opportunities for pilot interventions under the Wildlife TRAPS project, WWF and TRAFFIC are leading a separate project in Japan and the United States focused on trade in exotic pets. This project aims to define criteria for safe, sustainable and traceable exotic pets, guiding consumers away from species that present risks to conservation and human health and towards species that can be traded and kept safely and sustainably. Collaborating with this project may allow the Wildlife TRAPS project to better understand pet trade as an important example of live animal trade thus far underexplored by the Wildlife TRAPS project. The exotic pet project's system of categorising the suitability of different species may also provide a practical model for communicating safety and sustainability risks with the public, with stakeholders in trade and with policymakers under the scope of the Wildlife TRAPS project.

Tanzania and Vietnam are two promising national contexts to pilot a range of practical interventions

Wild meat Burgers in Borough Market, London

ANNEXES

ANNEX I: FURTHER CASE STUDY EXAMPLES

OSTRICH MEAT TRADE: RISK MITIGATION MEASURES, LEGISLATION, AND MEAT QUALITY STANDARDS

Disease Risk Mitigation Measures

Key mitigation measures to reduce the risk of disease propagation at the Critical Control Points (Figure 10) were as follows:

1) Tagging and vaccinating (for Newcastle disease) each ostrich under the age of four months before any movement to a raising farm[213 214]. Tags contain a unique identification number which allows the ostrich to be traced to the farm of origin. When on the raising farm, ostriches are tested for AI at least once every six months. Testing rates are much higher on slaughter farms, usually every 21-28 days; this is dependent on slaughter bookings, as the pre-movement tests are only valid for 21 days after blood sampling, and these tests are a critical requirement for the issue of a permit to move to the slaughterhouse. Moreover, testing is mandatory before the movement of any flock of birds. Importantly, all ostrich farms in South Africa are tested irrespective of the type and scale of the production system. Testing is done on a biannual basis at a minimum. The birds are also divided into population groups which are additionally tested. All pre-movements are tested in the population group moving and any other population groups on the farm at that time. Post movement testing is also done if the birds are not slaughtered;

2) To limit contact between waterfowl and ostriches, farmers often create their own large feed pellets (~8 mm) to make them inaccessible to waterfowl;

3) Waterfowl-ostrich contact is further reduced by raising feed and water troughs and making them difficult to access for the wild birds and their webbed feet[215]; strategies such as piping, size, and height are all used;

4) Chlorinating water is a critical mitigating measure – waterpoints are a disease reservoir if not cleaned regularly and chlorinated. Birds clean their beaks inside water, and waterpoints act as a central point for disease transmission (if one bird is infected, then the pathogen can spread to other birds through the waterpoint);

4) Before ostriches are moved to a slaughterhouse, they are tested and quarantined for at least 14 days;

5) Once at the slaughterhouse, they are subjected to an antemortem inspection, then bled out;

6) Heat treatment is often applied as a final control step to eliminate any risk of AI in the meat sample[216 217].

Critical Legislation and Meat Quality Standards

The most important South African government document regulating ostrich production is veterinary procedural notice (VPN) notice number VPN/04/2012-01 (Revision 6.0). It is issued to State (provincial) veterinary officers and other stakeholders according to their functions and responsibilities. The most important meat quality standard controls from this VPN and the 2018a Department of Agriculture, Forestry and Fisheries (DAFF) report on the South African Ostrich Market Value chain[218] are summarised as follows (specific sections are provided in Table 1):

1. Abattoirs and packaging plants processing ostrich meat must be approved for ostrich meat exports to the EU. Annex H of VPN notice number VPN/04/2012-01 (Revision 6.0) is critical here. Specifically, an application to the provincial State veterinarian must be made to move ostriches from a registered ostrich farm to an EU-approved abattoir. The registered farm must have ascribed to *inter alia* quarantine (14 days), could not have been moved from another farm less than three months prior, and must have undergone Newcastle disease vaccination. Both DALRRD/DAFF and the trade partner/country require inspection of the facility.

2. The South African authority must inspect meat at abattoirs and certify ostrich meat products before exporting to the EU. Provincial State veterinarians collaborate with DALRRD to enforce legislation and control rules found within the South African VPN notice number VPN/04/2012-01 (Revision 6.0) and the EU rules highlighted in Table 1.

3. South African authority must test meat for residues.

4. Before slaughtering, ostriches must be quarantined for at least 14 days. Quarantine camps must be free of vegetation and ticks and have a three-metre area cleaned around the camp. Tick control efforts must accompany a bird before it is slaughtered (tick control is a measure to reduce the risk of Congo fever).

5. Birds are not allowed to have any hormonal treatments or stimulants used in their growth.

6. Newcastle disease vaccinations are mandatory, and certifications must accompany birds before their slaughter.

7. 10 km quarantine radius applied if Newcastle disease outbreak occurs. This means that all farms within this radius are no longer allowed to export their meat to the EU.

8. No organic materials like hay or sand may be used in transporting birds to the abattoir. Vehicles must be disinfected before returning from the slaughterhouse.

9. AI status of the farm where the birds originated from must be presented when the birds are slaughtered.

10. All birds should be tagged, indicating their origin and traceability – birds must come from registered farms – these farms should have been registered for at least six months before the slaughtering event. Before slaughter, the birds must have lived on a registered farm for at least three months. Pre-movement testing is mandatory for any movement, as is a permit, and movement can only take place to another registered farm. Slaughtering can only take place from registered farms.

The EU has a series of phytosanitary standards (quarantine and biosecurity measures to protect human, animal and plant life from pests and diseases and from additives, toxins and contaminants in food and feed; available here). The "EU import conditions for poultry and poultry products" is arguably the most seminal set of guidelines, containing specific council directives on the poultry trade and those relevant to the ostrich industry (available here, also summarised in Table 1):

Additional notable legislation governing the veterinary control of ostrich production in South Africa include:

A. Article 7 and Article 8(1)(a), (b), (c) and (d) of Directive 2002/99/EC – On the organisational, legal and operative structures of the animal health control system for which assurances and guarantees equivalent to EU legislation have to be provided.

B. Chapter 3.1 of the WOAH Terrestrial Code – On the authorities and the organisation and implementation of official animal health controls.

C. Article 2 of Regulation (EC) No 798/2008 – Definitions.

D. Articles 23(2), 24, 25, and 26 of, and Annex V to Directive 2009/158/EC - Conditions for importation into the EU of poultry and hatching eggs

E. Articles 2 and 5 and Annex I to Directive 2005/94/EC – On the definition of AI and the measures related to its notification.

F. Articles 3.1.2, 3.4.5 and 3.4.9 of the WOAH Terrestrial Code on the fundamental principles to ensure the quality of Veterinary Services, the availability of veterinary legislation related to their mandate and organisation, and the management of animal diseases.

G. Articles 10.4.1 and 10.9.1 of the WOAH Terrestrial Code defining AI (and the occurrence of infection with an AI virus).

TABLE 1

Central legislation from the EU commission and South African government for producing and regulating ostrich meat exports from South Africa. The main purpose, regulation name and a link to the documentation are provided.

Regulation name	International or Local (South Africa)	Purpose	Link to legislation
Animal Diseases Act, 1984 (Act 35 of 1984)	South Africa	If ostriches are to be kept on a piece of land or moved, the specified piece of land must be registered	https://www.gov.za/documents/animal-diseases-act-12-mar-2015-1128
VPN/04/2012-01(Revision 6.0)	South Africa	It is the farmer's responsibility (page 11) to ensure detailed information on ostrich farm compartments, make birds accessible to vets for testing, water point info, chlorination, etc., and inform provincial state veterinarian of any mortalities >5% of total numbers, etc.	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	A farm can only be registered if it adheres to biosecurity measures in annex G	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	If a farm has had AI activity > three times in 24 months, it is considered high risk, and re-registration is not possible	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	Only birds that have tested negative serologically for AI during the last six months and specifically in the previous 21 days are eligible for movement to another registered farm.	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	Ostriches need a flock movement passport and flock register number to be moved to another registered farm compartment.	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	Testing (routine six-monthly and pre-movement serological) is designed to detect the presence or absence of H5 or H7 AI strains	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	All birds > four months of age to be tagged	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	Vaccination against Newcastle disease must be done before ostriches are slaughtered, only tagged birds are eligible	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	Only ostriches moved into a tick-proofed enclosure before slaughter for 14 days are eligible for EU export certification (used to combat Crimean Congo Haemorrhagic Fever)	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	Only registered veterinary medicines are allowed for chemical residue testing (e.g., Production enhancers, growth stimulants).	https://tinyurl.com/56ke5ujn
Council Directive 2002/99/EC	European Commission	Details the animal health requirements for fresh meat. This Directive forms the legal basis for all animal health rules governing the production, processing, distribution, and introduction of products of animal origin for human consumption. It continues to provide harmonised rules and animal health guarantees for import into the EU of fresh meat.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0099
Commission Regulation (EC) No. 798/2008	European Commission	Details a list of third countries, territories, zones or compartments from which poultry and poultry products may be imported into and transit through the Community and the veterinary certification requirements.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008R0798
Commission Implementing Decision (EU) No 139/2013	European Commission	Details the requirements for the importation into the EU of birds other than poultry (captive birds).	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013R0139
Commission Regulation (EC) No. 798/2008	European Commission	Eligibility criteria for the import of poultry and poultry meat - most central of these tenants are the following: 1) Exporting countries must have a competent veterinary authority responsible throughout the food chain. The authorities must be empowered, structured and resourced to implement effective inspection and guarantee credible certification of the relevant veterinary and general hygiene conditions; 2) Country of origin must fulfil the relevant animal health standards. This implies that the country should be a member of the World Organisation for Animal Health (WOAH); 3) Veterinary services must enforce regulations; 4) Imports only approved from registered establishments (e.g., slaughterhouses, cutting plants etc.); 5) Veterinary services must have at their disposal a series of labs for testing; 6) National authorities must guarantee hygiene and public health requirements are met.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008R0798
Commission Regulation (EC) No. 798/2008	European Commission	Details the veterinary requirements which must be fulfilled when exporting poultry and certain poultry products and a list of those third countries from which imports of these commodities are authorised.	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008R0798
VPN/04/2012-01(Revision 6.0)	South Africa	If one is not producing ostrich products for EU export, then they are exempt from VPN requirement to provide pre-slaughter tick-proofed isolation camps as detailed in Annex G, points 18-24 or to obtain and keep copies of movement documentation for the movement of ostriches to an EU abattoir on condition that ostriches are not tick-infested when they are moved to a slaughterhouse or abattoir.	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	Ostriches <6 weeks old exempt from serological testing before movement	https://tinyurl.com/56ke5ujn
VPN/04/2012-01(Revision 6.0)	South Africa	Breeder birds do not have to be subjected to serology or PCR testing as long as movement takes place from registered breeding farm to registered breeding farm	https://tinyurl.com/56ke5ujn

FISHERIES: MARINE STEWARDSHIP COUNCIL

The Marine Stewardship Council (MSC), a consumer label for sustainably harvested seafood, provides a valuable model for implementing and marketing traceability internationally. As a voluntary certification scheme, the primary effort of collecting data for traceability falls on the producing companies, who must show that the fishery from which they source their seafood and the fishing practices they use are sustainable, as verified by regular third-party audits[219].

To be eligible to participate in the MSC certification, the company and the fishery it sources from must get a pre-assessment from a third-party organisation to certify

their sustainability. The cost of these initial steps can range from $10,000 to $100,000, depending on the complexity of the fishery[220].

For fisheries that do not readily meet MSC's standards, participation in Fishery Improvement Projects[221] (FIPs) creates a five-year window for these fisheries to progress towards the standard. Some fisheries have tried to reap the programme's benefits by stating they are in the FIPs class without making improvements and remaining in this class beyond the five-year window for improvement; extra auditing is needed to verify that these actors are progressing[222]. This transitional approach towards compliance may be a good model for wild animal trade actors with a low risk of EIDs and are economically important to maintain.

A new MSC requirement now mandates that a company's various types of fishing gear must all be MSC-approved so that actors cannot simultaneously harvest both MSC and non-MSC products[223]. Given the mixing of legal and illegal practices that is widespread in the trade of wild mammals and birds, such as the laundering of illegal wild-caught specimens into legal captive breeding sites (wild animal farms), it is vital to establish similarly tight requirements for wild animal trade chains.

If the pre-assessment for participation in MSC is successful, the company then implements traceability by imposing a digital data collection solution, such as blockchain, for all their upstream suppliers. MSC requires every link in the supply chain to obtain certification for chain of custody to make sure products can be traced back to their source. Rather than using MSC's platform to enter data, MSC asks businesses to maintain their own data systems. MSC later pulls businesses' data into their system for verification. The businesses must keep track of their national legal regulations and requirements for export, as applicable. Rather than requiring specific data elements, MSC instead sets bounds for what a company's information needs to demonstrate to comply with MSC's sustainability standards[224].

The main cost of participating in MSC goes to third-party auditor companies. MSC charges an annual royalty of 0.5% for applying the MSC logo to the company's seafood products and packaging, revenue which feeds back into MSC's research and development[225].

A third-party certification scheme like MSC that is not fully integrated into a company's supply chain can make it challenging to track down issues that arise, but MSC does have procedures to deal with such issues. If an operator is noncompliant, MSC labels are immediately separated from that company's products. A food safety issue will trigger a non-conforming product procedure; triggering a recall. Customers and retailers must then be notified within two days to recall products and relabel them. Upon receipt of any MSC products, even outside of a recall situation, a retailer must check that their suppliers' MSC documentation is valid. MSC conducts random sampling of products and forensic testing for DNA species identification and is now developing new approaches to test that product claims match their catch location[226].

Due to the onus of data collection falling on the producer for MSC certification and the relative expense of its required audits, MSC's approach to traceability is best suited to large scale producers. These large-scale producers are often already using traceability practices for other systems, whether to prove their data to access export markets or participate in other standards, like FairTrade and halal. For smaller-scale producers, the expense of setting up their own data collection technology and funding audits can be prohibitive, so simpler mobile phone App-based traceability tools like SharkTrace[227] and Abalobi[228] offer more accessible solutions.

PLANT TRADE: FAIRWILD

FairWild is a voluntary certification scheme for wild-collected plant ingredients. The certification aims to support the ecological sustainability of wild plant harvesting and fair business practices to support the livelihoods of harvesters[229]. Like MSC's system of FIPs discussed in the previous section, FairWild offers producers opportunities for continuous improvement towards the level of certification, gradually increasing performance over the first several years of participation as guided by annual audit feedback[230]. These potential suppliers can choose to be listed on FairWild's website to have their efforts recognised by prospective buyers[231]. In these first few years of engaging with a certification scheme and working to improve practices toward its standards, small-scale producers typically need funding support from donors or larger companies. The cost of improvement can be burdensome when the producer is not yet able to achieve certification and the sales growth it may bring.

FairWild's criteria for traceability and sustainable collection, shown in the charts below, provide a helpful starting point in considering the level of detail needed to ensure traceable and sustainable wild product sourcing:

TABLE 2

FairWild's traceability criteria. Source: FairWild Standard Version 2.0: Performance Indicators (2010)

CP N°	Control Points 10.2 Traceability	MAX	Score
10.2.a	Deliveries / purchases are registered in a **buying record** which states at least the date, the collectors name or code, collection area, delivered quantity and product details and the FairWild certification status: (0) no or very incomplete records; **(1=M)** basic records with at least name and quantities as well as collection area for monitoring activities; (2) adequate, reliable records; (3) very good records.	3 **1=M**	
10.2.b	The collector is issued a **receipt**, which indicates at least the date, collectors' name (or code), species and product, delivered quantities and FairWild certification status: (0) no receipts; (1) very simple receipts, not fully implemented; (2) adequate receipts; (3) very well-documented purchase system.	3	
10.2.c	There is appropriate **documentation of central processing / packing activities** (processing / packing diary) to allow traceability of batches: (0) no documentation; (1) very basic / slightly incomplete; **(2=M from Year 2)** adequate record; (3) advanced documentation system.	3 **2=M from Yr 2**	
10.2.d	For every processed product (i.e. cleaned, sorted, cut, sifted material) the **processing ratio** (collected quantities to final processed weight) and **composition** (in case of multi ingredients products) is known: (0) not known; (1) some basic information; (2) documented; (3) very good processing documentation**.**	3	
10.2.e	**Collection and post-collection identification, labelling, and record keeping procedures allow to trace back each batch of goods to the area where it was collected:** (0) no traceability back to collection area; (1) very basic / not yet consistently implemented; **(2=M from Year 3)** simple system ensures traceability to collection area; (3) consistent lot number system.	3 **2=M from Yr 3**	
10.2.f	**Purchase or collection of the same target species outside of FairWild certification scope:** (0) the collection operation collects same species outside FairWild scope; (**1=M)** same products are bought in or collected in other regions: clear separation and labelling procedures, well documented purchase and sale; (2) the collection operation does not buy in or collect the same species outside FairWild certification; (3) entire collection operation activity is FairWild certified. *If not applicable → (3)*	3 **1=M**	
10.2.g	**Products are labelled correctly** when leaving the collection operation to the next buyer: FairWild certification status of the products, name of product, lot number or code of purchase centre: (0) no consistent labelling; (1) some improvements needed; (2) correct labelling, or alternatively this information is given on accompanying papers that can be clearly linked to the respective lot; (3) lot number system and very good labels.	3	
10.2.h	**Documentation of all exports and local sales** allow a full verification of product flow: (0) no export / sales documents; (1) poor / incomplete records; (2) detailed invoices with quantities, product details, lot numbers or similar; (3) data base and detailed invoices.	3	
10.2.i	**Invoices and shipping documents specify the FairWild certification** status of the products; (0) no reference; **(1=M) certification status indicated on invoice;** (2) quality on all shipping documents; (3) very good labelling and traceability system.	3 **1=M**	
10.2.j	**Invoices or sales contracts specify the FairWild Premium:** (0) not specified and not even defined; (1) agreed but not specified in documents; (2) adequately documented.	2	
10.2.k	**Transaction certificates** for all sales of the certified products issued by certification body: (0) none; (1) for some sales; (2) available for all FairWild sales.	2	

TABLE 3

FairWild's criteria for sustainable collection. The wild-collection operation ensures that only trained and competent collectors collect the target resources. Source: FairWild Standard Version 2.0: Performance Indicators (2010)

CP N°	Control Points 9.3 Implementation of sustainable collection measures by collectors	MAX	Score
9.3.a	**Collectors' registers are available** in order to make sure that all collectors are well trained and know the rules of collection: (0) no registers; (1) incomplete registers; **(2=M from Year 2)** adequate and complete registers with full names, code number, address / village; (3) good registers with names of household members who also actively participate in collection.	3 **2=M from Yr 2**	
9.3.b	Products are **only bought from registered and trained collectors:** (0) no purchase system in place or system not implemented at all; (1) purchase system in development; **(2=M from Year 2)** purchase system ensures that products are only bought from registered collectors; (3) very well organised purchase system.	3 **2=M from Yr 2**	
9.3.c	Under the name of one registered collector **only his / her immediate family members** (members who live in same household) **are active in the collection**. The activity of these collectors is supervised and found OK (same rules as for registered collectors): (0) no / minimal information on collectors; (1) unsupervised "umbrella collectors" (one collector registered with unknown number of actual collectors); **(2=M from Year 3)** only members of same household collect and receive information from main collector; number of collecting household members known / documented; (3) all collectors are known by name, all people actively collecting are encouraged to participate in trainings.	3 **2=M from Yr 3**	
9.3.d	The **collectors** are adequately **informed about the boundaries** of the collection area and about the **areas excluded from collection** as well as small-scale contamination sources where organic products may not be harvested: (0) collectors not informed / aware of such boundaries; **(1=M)** basic understanding and no major inner boundaries owing to contamination; (2) adequately informed; (3) collectors are very knowledgeable.	3 **1=M**	
9.3.e	The **collectors are trained, knowledgeable and competent** in the following aspects: · Plant to be collected (including which parts, minimum quality requirements etc.) · Sustainable collection methods (as per internal rules) · Post-harvest handling of collected material (0) not aware of internal collection and handling instructions; **(1=M for Year 1)** basic understanding; **(2=M from Year 2**) collectors are trained, knowledgeable and competent in the implementation of internal instructions; (3) collectors are very knowledgeable.	3 **1=M Yr 1 2=M from Yr 2**	
9.3.f	**Implementation of the collection instructions**: **harvest methods, harvested parts:** (0) not implemented; **(1=M Year 1&2)** basic implementation of collection instructions; **(2=M from Year 3)** adequate implementation management in place; collectors collect according to collection instructions; (3) collectors well familiar with collection instructions.	3 **1=M Yr 1&2 2=M from Yr 3**	
9.3.g	**Evidence of collection frequency based on physical visits and interviews with collectors:** (0) clearly higher frequencies on certain sites, collectors not aware of frequency restrictions AND indication of over-harvesting; **(1=M Year 1&2)** no indication of overall over-harvesting, but collectors not aware of frequency limitations or commonly harvesting more often than instructed in certain areas / plots; **(2=M from Year 3)** harvest as per official collection frequency, no over-harvesting evident even on highly frequented spots; (3) very low impact of harvest activity. ***High Risk species*** *→ see additional indicator 9.3.g (Part II)*	3 **1=M Yr 1&2 2=M from Yr 3**	
9.3.h	**Collectors do not collect the same product in quality and quantity not compliant with FairWild requirements (outside collection area / not according to the rules of this Standard):** (0) collection of same target plant for different buyer companies and without consideration of collection rules; (2) all target plants collected are collected basically according to the internal collection instructions; (3) only FairWild collection according to FairWild management plan.	3	
9.3.i	**Effective measures are taken to ensure that any identified contaminated areas or areas with intense agriculture are excluded from collection** (collection instructions, training of collectors) (0) collection from contaminated areas (1) no actual measures taken, but clearly no collection from any contaminated areas **(2=M from Year 2)** no sources of contamination OR effective measures ensure that no collection from contaminated areas. *If not applicable or if certified organic → (2)*	3 **2=M from Yr 2**	
9.3.j	**Implementation of the collection instructions:** maximum quantities: (0) no system in place; (1) basic system; **(2=M)** adequate implementation management in place; collectors only collect strictly according to collection rules and are informed on maximum quantities; (3) collectors are fully aware of collection rules and actively contribute to their implementation through discussions and monitoring activities.	3 **2=M**	

ANNEX II: BIBLIOGRAPHY FOR THE LITERATURE REVIEW

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ANNEX III: LIST OF INTERVIEWEES

- Dr Celia Abolnik, Scientist – Professor NRF-DST South African Research Chair in Poultry Health and Production
- Steven Broad, Consultant – 4responsible, IUCN Sustainable Use and Livelihoods Specialist Group
- Peter Coetzee, Chairman – Agri Western Cape Branch (South Africa)
- Dr Sinh Dang-Xuan, Post-Doctoral Scientist ¬– International Livestock Research Institute
- Dr Anel Engelbrecht, Scientist – Western Cape Department of Agriculture (South Africa)
- Dr Amanda Fine, Director of One Health – Wildlife Conservation Society
- Dr Tiggy Grillo, National Coordinator – Wildlife Health Australia; Scientific Officer Wildlife Health Programme – WOAH , Co-chair, IUCN Wildlife Health Specialist Group
- Dr Adriaan Gutteridge, Fisheries Assessment Manager – Marine Stewardship Council
- Faye Hartman, Consultant – ProFound
- Douglas Jobson, General Manager – Macro Meats Adelaide
- Dennis King, Executive Officer – Kangaroo Industry Association of Australia
- Dr Richard Kock, Professor of Wildlife Health and Emerging Diseases – Royal Veterinary College, University of London; Former Co-chair – IUCN Wildlife Health Specialist Group
- Dr Hu Suk Lee, Veterinary Epidemiologist – International Livestock Research Institute
- Shen Yan Liow, Senior Supply Chain Standards Programme Manager – Marine Stewardship Council
- Dr Michael O'Leary, Senior Infectious Diseases Advisor, USAID Viet Nam
- Dr Adriaan Olivier, Industry Veterinarian – South African Ostrich Business Chamber
- Dr Pawin Padungtod, Senior Technical Coordinator – FAO Emergency Centre for Transboundary Animal Diseases
- Dr Ekta Patel, Scientist and Communications Manager for Biosciences – International Livestock Research Institute
- Joey Potgieter, Chairman – Ostrich Producers Organization (South Africa)
- Mark Ryan, Former Deputy Director General – International Council for Game and Wildlife Conservation
- Dr Fred Unger, Senior Scientist – International Livestock Research Institute

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