CSIRO PUBLISHING

COLLECTION | REVIEW
https://doi.org/10.1071/AN23431

ANIMAL PRODUCTION SCIENCE

PERSPECTIVES ON ANIMAL BIOSCIENCES

Perspectives on progression of transboundary disease, one health and ecosystem health management in the Greater Mekong Subregion and beyond

Peter Andrew Windsor[A,*]

For full list of author affiliations and declarations see end of paper

***Correspondence to:**
Peter Andrew Windsor
The University of Sydney, Sydney School of Veterinary Science, Camden, NSW 2570, Australia
Email: peter.windsor@sydney.edu.au

Handling Editor:
Stephen Walkden-Brown

Received: 22 December 2023
Accepted: 26 June 2024
Published: 18 July 2024

Cite this: Windsor PA (2024) Perspectives on progression of transboundary disease, one health and ecosystem health management in the Greater Mekong Subregion and beyond. *Animal Production Science* **64**, AN23431. doi:10.1071/AN23431

ABSTRACT

Livestock production in the Greater Mekong Subregion (GMS) reflects the inefficient smallholder 'keeper' system that has been slow to adapt to the rapidly expanding demand for animal protein-sourced foods in the region as urban economies have flourished and food preferences altered. The prolonged surge in demand, with only modest increases in local production, has increased the movement of animals and products into and from the GMS, accompanied by surging risks of transboundary animal disease (TAD) incursions, including the one health (OH) threats of zoonoses and antimicrobial resistance. As a consequence, the region has been subjected to epidemics of highly pathogenic avian influenza (HPAI), new strains of foot-and-mouth disease (FMD) virus, with recent incursions of African swine fever (ASF), lumpy skin disease (LSD), porcine reproductive and respiratory syndrome (PRRS) and risks of peste petits ruminants (OPR) occurring in Southeast Asia (SEA) and beyond. These incidents reflect inadequate biosecurity, a sustainability issue that was clearly of relevance in the covid-19 pandemic, reflecting ecosystem health (EH) deficits, including land-use issues and unregulated trading in wildlife-sourced and poorly processed foods through the predominant 'wet markets'. These challenges are increasingly confounded by slow adaption to the impacts of the climate crisis, including flooding, drought, crop failures and hypothermia episodes. The increase in animal and product movements enhances disease transmission risk, yet coincides with emerging concerns of greenhouse-gas emissions (GHGe) from livestock production, especially from large ruminants, as the world attempts to find pathways in managing the climate crisis. Despite the prolonged collaborative efforts of the SEA China FMD program from 1997 to 2023, a recent review confirmed persistent deficits in biosecurity, vaccine resourcing, disease surveillance, engagement of farmers, and national emergency disease-response capacities. A major project is about to fund major improvements in livestock value chains in Cambodia, including more effective biosecurity, surveillance and emergency disease-response capacities for TADs, antimicrobial resistance (AMR) and zoonoses. Similarly, a private-sector investment in Laos has developed a more climate-resilient livestock-feeding system that decreases GHGe impacts from ruminant production. These developments are likely to extend beyond both countries and be potentially transformational for the livelihoods of many of the poorest citizens in the region.

Keywords: abatement, agricultural development, emissions control blocks, foot-and-mouth disease, large ruminants, methane, parasites, zoonoses.

Introduction

It has been estimated that although family farms produce ~80% of the world's food on farms of variable size, smallholder farms or those that are smaller than 2 ha, produce only ~32% of the world's food supply, using ~24% of the world's agricultural land (Ritchie 2021). Although focused mostly on cropping and traditionally rice cultivation

Collection: Sustainable Animal Agriculture for Developing Countries 2023

in Southeast Asia (SEA), smallholder farmers also contribute to world meat production and this has been increasing as large ruminants previously used for draft have become available for meat following widespread mechanisation for rice cultivation (Windsor 2011). Approximately 90% of meat is obtained from chickens, pigs and cattle, reaching 357 million tonnes in 2021, compared with 124 million tonnes in 2000 (Food and Agriculture Organisation (FAO) 2023*a*). The 4% increase in production between 2020 and 2021 was the fastest over the 2000–2021 period. Smallholder farmers also contribute to the global production of bovine milk, although this is a recent development in SEA. Cattle and buffalo contributed 96% of the global milk produced in 2021, increasing to 884 million tonnes. Asia was the largest milk-producing region in 2021, with 44% share of the total, a 142% increase between 2000 and 2021, from 159 million tonnes to 384 million tonnes, although this mostly occurred in India (126 million tonnes), with a 23% share of the global total (Food and Agriculture Organisation (FAO) 2023*a*).

Increasing the productivity of smallholder farming is considered a crucial step in countries transitioning from poverty to middle incomes (Ritchie 2021). Because these farming families are some of the poorest people in the world, mostly located in developing countries, improving their outputs and incomes is important, even if they are likely to continue to produce less than the non-smallholder farming sector. Enhancing livestock farming in developing countries includes both use of large ruminants for meat and, more recently, milk production from buffalo that are increasingly no longer required for cultivation (Windsor *et al.* 2021*a*; Laos Buffalo Dairy (LBD) 2023). Both commodities are now providing important pathways in the amelioration of rural poverty, particularly in the Greater Mekong Subregion region (GMS) of SEA (Windsor 2011). This includes the Lao People's Democratic Republic (Lao PDR, Laos) and Cambodia, where a majority of the population live in rural communities, often remotely, with minimal services available. These farming families depend on their livestock as 'cash banks' and for household food security, providing manure as fertiliser and increasingly for energy through biodigestors, with some large ruminants also being valued for transportation and, more recently, provision of milk for improved childhood development (Laos Buffalo Dairy (LBD) 2023).

Sustained increases in global demand for meat and milk have driven both increasing production and supply via trade, with Asia becoming a net importer of all commodity food groups other than fish in 2021 (Food and Agriculture Organisation (FAO) 2023*a*). Increases in both imports and local production of livestock and their products to meet increasing demand in the GMS, more broadly in SEA, and, importantly, in countries beyond this region, require improved adoption of existing 'best practice' animal-husbandry technologies (Young *et al.* 2014). This includes improvements in feeding systems, health interventions, reproductive management, housing, manure management and, importantly, marketing and safe processing of livestock and their products (Windsor *et al.* 2021*a*). Such improvements have been estimated to potentially assist the global livestock sector to reduce greenhouse-gas emissions (GHGe) by as much as 30% (Food and Agriculture Organisation (FAO) 2018).

Global animal-protein production is associated with total emissions of 6.2 Gt of carbon dioxide equivalents (CO_2eq), or ~12% of the estimated 50–52 Gt CO_2eq of total anthropogenic emissions in 2015 (Food and Agriculture Organisation (FAO) 2023*b*). Cattle are the largest contributors to GHGe, producing ~3.8 Gt CO_2eq per year, or 62% of all livestock emissions (Food and Agriculture Organisation (FAO) 2023*b*). Pigs, chickens, buffaloes and small ruminants contribute to 14%, 9%, 8% and 7% respectively, of livestock's overall emissions. Approximately two-thirds of global emissions are allocated to meat production across all species, with approximately one-third being related to the production of feed inputs, including fertiliser and farm chemical use. It has been noted that variations in emission intensity (EI; kg CO_2eq/kg product) or 'carbon footprint' across countries, species and production systems, reflect differences in breeds, management practices, feed quality and environmental conditions. Addressing these differences offers potential pathways for reducing the carbon footprint of the livestock agrifood systems (Food and Agriculture Organisation (FAO) 2023*b*).

Financial motivation to improve the efficiency of cattle and buffalo production has followed an upward trajectory for two decades, particularly in the GMS, where cattle and buffalo liveweight price trends have continued to increase because of growing regional beef consumption (Windsor *et al.* 2021*b*). This has created opportunities for some smallholder famers to significantly improve their livelihoods, with fattening operations and small feedlots emerging in some locations. However, many livestock farmers in developing countries have low animal-husbandry skills, minimal nutritional, biosecurity, animal-disease and reproductive management knowledge, have poor access to markets and high rates of illiteracy (Nampanya *et al.* 2014*a*; Young *et al.* 2014; Windsor *et al.* 2021*b*). As extension and veterinary services in GMS countries are usually limited, smallholders often have suboptimal abilities for use of the nutritional, health and reproductive interventions that published research has demonstrated can greatly improve efficiency of livestock production. For example, in Laos and Cambodia, fewer than 60% of farmers are using vaccines on cattle and buffalo and these are typically administered to only half the herd or less, preventing the establishment of herd immunity for haemorrhagic septicaemia (HS; Kawasaki *et al.* 2015) and foot-and-mouth disease (FMD; Rast *et al.* 2010; Nampanya *et al.* 2014*a*, 2014*b*). This occurs despite the evidence of socioeconomic benefits and successful outcomes from implementation of household and regional vaccination programs (Young *et al.* 2016; Nampanya *et al.* 2018).

This paper documents the reflections presented in a plenary talk delivered at the International Conference on

Sustainable Animal Agriculture for Developing Countries biennial (SAADC) conference in Vientiane, Laos, 21–24 November 2023. The aim was to provide a perspective on the progress in managing risks of transboundary animal diseases (TADs), plus one-health (OH) and ecosystem-health (EH) concerns in the GMS; however, owing to the increasing inter-connectedness of countries in the SEA region, especially for trade in livestock and their products, the term 'GMS and beyond' is preferred (Mekong Livestock Research and Beyond (MLRB) 2023). The paper is informed by 'hands-on' experiences in applied research in the region that commenced in 1998, and continues. This work is important because SEA is considered the most likely source of TAD risk to Australia (Blacksell *et al*. 2019). The objective was to share knowledge of the dynamic nature of both FMD and other emerging infectious diseases (EIDs) including OH and EH concerns of farmed animal populations in the region, plus describe interventions that may assist future progress. It is important to recognise that addressing regional TAD risks requires an understanding that because livestock production systems in SEA remain so very different from those of Australia, progressing TAD control and OH and EH concerns in the GMS and beyond is very challenging.

The persistent challenges of traditional livestock farming in the GMS

Livestock diseases, particularly TADs and zoonoses, increasingly threaten the lives and livelihoods of the often marginalised, smallholder farming communities in the GMS. Diseases pose significant risks to farming families, their livelihoods and, increasingly, the global human population, particularly when animal pathogens cross species barriers into humans as zoonoses. Further, the antimicrobial use (AMU) of therapeutics for livestock disease management, often inappropriately contribute to residues and/or risk of antimicrobial resistance (AMR). These emerging OH threats have been of concern for decades, particularly following emergence of strains of highly pathogenic avian influenza (HPAI) viruses (World Health Organization (WHO) 2017; World Organisation for Animal Health (WOAH) 2023*a*), henipaviruses (World Health Organization (WHO) 2018) and the SARS-associated coronavirus causing severe acute respiratory syndrome (SARS) in 2003 (World Health Organization (WHO) 2023), suggesting a global pandemic was likely to emerge, possibly in the vicinity of the GMS (World Health Organization (WHO) 2023). These predictions heralded arrival of the most unfortunate of OH coronavirus disasters that emerged just to the north, when covid-19 emerged in Wuhan and rapidly spread globally.

To control animal diseases, implementation of disease-control policies that facilitate programs focusing on promoting positive behavioural change by individual smallholder farmers is required. The aim is to use knowledge-based and other interventions to encourage adoption of disease prevention, through vaccination and biosecurity, and other disease-management interventions, including parasite control. Unfortunately, these programs often fail or deliver suboptimal outcomes (Windsor and Hill 2022).

Why has improved livestock health, productivity and welfare for food security and rural poverty alleviation continued to be so difficult to deliver in developing countries? Although management of TADs/OH/EH is strongly inter-related, these require effective disease surveillance and efficient response capacities. Attempts to continually improve these capabilities have been numerous, with a long list of research and development programs having been delivered. However, it is likely that the generally piecemeal improvements of in-country and regional disease-management mechanisms and capacities has largely failed to keep pace with the rapid increases in risks to food security and health in the GMS and beyond. These have emerged following both the impressive economic development in the region (Miller *et al*. 2018; Blacksell *et al*. 2019) and the increasing vulnerability of livestock production to climate-change crisis risks, including episodes of severe hypothermia (Khounsy *et al*. 2012).

Although it is apparent that the increasing TAD/OH/EH risks reflect the rapid rise in consumer demand from changing dietary preferences, driving increased animal and product movement, this has been accompanied by climate-change impacts, driving increased vulnerability of livestock agrifood production systems to both ecosystem and disease shocks. Epidemics of African swine fever (ASF; Matsumoto *et al*. 2021), incursions of new FMD virus strains (Blacksell *et al*. 2019), occurrence of lumpy skin disease (LSD; Ratyotha *et al*. 2022) and risk of peste petits ruminants (PPR; Burns *et al*. 2019) with persistent outbreaks of HPAI in the GMS and beyond (Pfeiffer *et al*. 2013) appear to both threaten food insecurity and are likely to increasingly be caused by it. This increasingly complex situation is now confounded with an expectation that the high-EI livestock agrifood systems of the GMS will need to find means of amelioration of the GHGe that result from the mostly inefficient smallholder farms (Windsor *et al*. 2021*a*; Windsor and Hill 2022). The EIs of meat production from cattle in Laos, Cambodia and Indonesia at 102.9, 88.51, 58.72 respectively, are comparatively much higher than the EIs of global average and Australian beef meat production systems at 30.28 and 22.01 respectively (Food and Agriculture Organisation (FAO) 2023*a*).

Problem definition in the GMS livestock systems

Ongoing applied field research has been conducted by our Mekong Livestock Research and Beyond (Mekong Livestock Research and Beyond (MLRB) 2023) team for over one and a half decades in Laos and Cambodia, documenting the

systematic constraints that influence the understanding by farmers of disease-related risks, plus the household-level decisions involved in investing in animal-disease control. The work has involved numerous longitudinal livestock production and health studies and participatory observations, accompanied by in-depth interviews and focus-group discussions, involving farming families in numerous research-site villages in both countries (Nampanya *et al.* 2014*a*, 2014*b*, 2014*c*; Young *et al.* 2014). Although there were many partners involved, progress depended on key relationships in both countries, particularly Dr Syseng Khounsy of the Department of Livestock and Fisheries in Laos (DLF) and Dr Suon Sothoeun of the General Directorate of Animal Health and Production in Cambodia (GDAHP). Numerous collaborations with sharing of insights and training materials with other research teams and international agencies, especially WOAH and FAO, have also contributed to the learning that has informed this process (Australian Centre for International Agricultural Research (ACIAR) 2012, 2013; Nampanya *et al.* 2014*c*, 2017, 2018).

This research identified the ongoing structural constraints of low health and husbandry knowledge, weak veterinary health and rural extension systems, poor supply-chain infrastructure plus limited access of farmers to markets and low-interest credit. These and other constraints prohibit more progressive farmers from gaining the necessary knowledge for application of disease-prevention practices, inhibiting abilities to invest in risk management and increasing their economic vulnerability. Such constraints drive behaviours that are often recognised as 'high risk' for disease emergence and spread, including sale and purchase of diseased stock, lack of vaccination, failure to implement quarantine and hygiene, failure to report disease outbreaks to animal-health authorities, inadequate use of anthelmintics and, importantly, excessive and inappropriate use of antimicrobials (Windsor *et al.* 2020). These behaviours lead to many small- and medium-scale farmers in the GMS and beyond remaining trapped in a cycle of poverty, poor productivity and, commonly, ill health for both animals and humans (Windsor 2011; Nampanya *et al.* 2014*a*, 2014*b*, 2014*c*; Young *et al.* 2015).

Whereas it is challenging to address the complexities of these issues, if production deficits and disease impacts are to be sustainably ameliorated, it has been important to understand the motivations and resistance characteristics of smallholder farmers in the GMS. Many farmers still consider disease outbreaks as an 'act of god' and that disease control is either unmanageable or a government responsibility. We have learned that whereas the knowledge required to control disease mostly requires implementation of risk-management interventions, particularly vaccination and biosecurity, these strategies are not recognised by farmers as ways for them to generate income, or more importantly, decrease their workloads, particularly when their thinking is that disease is something that is to be treated, rather than prevented. This means that many disease-control advisory programs have and will continue to fail because they are considered unaffordable.

Recognising motivations and resistance to change

Our initial work identified that successful implementation of animal-health and -production programs required farmer learning that is both participatory and motivational (Nampanya *et al.* 2012). This was assumed to be the introduction of interventions that assisted smallholder farmers to recognise socioeconomic improvements, particularly increased household income. Because this often involves work that is outside of the immediate disciplines of the animal-health personnel, it required larger teams with nutritional, marketing and social science expertise, including gender-focused strategies (Bush *et al.* 2014*a,* 2014*b*; Nampanya *et al.* 2014*c*; Mekong Livestock Research and Beyond (MLRB) 2019). The experiential learning acquired was that once money was being made and workloads decreased by smallholder farmers from feeding their animals properly using forage plantations and more recently molasses blocks, they then began to understand that they should protect this 'investment' of labour and they became more receptive to the necessity of adopting health interventions. Of importance was that the successful adoption of some interventions was due to motivations other than income generation, particularly the 'time-savings' acquired, enabling more time for other farming activities and improved education of children now spending less time seeking feed for the animals. The introduction of forages decreased the labour required to provide adequate 'cut and carry' feed and, recently, the availability of molasses blocks ensured easier animal management of animals with more rapid return from open grazing to access the blocks (Mekong Livestock Research and Beyond (MLRB) 2023). Clearly, understanding the implementation of animal production- and health-improvement programs is the recognition that motivations and resistance assumptions may not always be what was initially expected.

This experience was first observed in the successful FMD eradication program in the Philippines in 1998–99, where it was found that although training on FMD and biosecurity was considered important, the majority of farming households mainly wanted to know how to improve the feeding of their pigs. Supplementing their use of kitchen waste or swill enabled them to obtain more money from their pigs and the cooking of the kitchen waste created a biosecurity intervention that prevented FMD virus transmission (Windsor *et al.* 2011). Similarly with Cambodian cattle from 2007, forages were introduced for feeding and fattening of cattle, taking several years to establish. These plantations eventually proved to be very successful in motivating farmers to adopt change (Nampanya *et al.* 2012), resulting in the development of a robust market for forages for cattle feeding. Of importance were the socioeconomic impacts of forages for rural families,

with time saved in efficiently feeding their animals and more readily available collection of manure for fertiliser and/or energy. Numerous families in our research programs are now able to afford to send their children to university from the additional funds achieved from moving from subsistence smallholder 'keepers' to more productive small–medium cattle-raising enterprises (Mekong Livestock Research and Beyond (MLRB) 2018).

What are the solutions?

Reflections from the learning acquired during the studies conducted by our team members, collaborators and the findings of others working in the GMS livestock sector, as briefly described above, has led to the conclusion that future efforts require delivery of the following three major strategies:

1. Transitioning of smallholder livestock 'keepers' to production efficiencies with a food-safety focus,
2. Applying lessons learned on biosecurity and other disease-control strategies learned during the years of regional collaboration through the SEA China FMD (SEACFMD) program (WOAH) and sharpened by covid-19 responses,
3. Prioritising development of a sustainable food-security system by all stakeholders is required with delivery of large livestock development projects to upgrade capacities and infrastructure for production and processing, plus encouraging commercial investments that can assist delivery of Point 1 (above).

Transitioning smallholder keepers to production efficiencies with food safety

The slow adaption to modern livestock production systems in the GMS reflects that smallholders generally see large ruminants as a 'cash reserve' for sale when the household needs funds, including health issues or festivities. Few smallholders consider their large ruminants as a food product that can be value-added and directed at a premium market aligned to the rapidly rising demands for increased quantity and quality of animal-sourced foods. That this transition is important has been increasingly evident, as the increasing risks of TAD/OH/EH incursions have resulted in a cascade of epidemics in the GMS, particularly from HPAI, ASF, LSD and importantly, new FMD virus strains. Although the most recent strain of FMD, the O/ME-SA/Ind-2001e sublineage, has been predominant in the GMS and beyond recently (Ryoo *et al.* 2021), other strains are still circulating and there is an emerging risk of FMD serotype SAT2. FMD serotype SAT2 usually circulates only in Africa, although it was identified in western Eurasia and the Near East in February 2023, with risks to the GMS where most animals are fully susceptible to infection by this virus. A recent qualitative risk assessment (McLaws *et al.* 2023) found that the likelihood of spread of the FMD SAT2 to unaffected countries via key risk pathways was plausible, particularly with the persistence of informal movements of live animals and common grazing. These biosecurity deficits enable direct live-animal contact for effective FMD virus transmission. Production losses and cost-of-control measures of an incursion of FMD SAT2 were estimated at USD 3.6–6.5 billion, depending on the extent of spread within the region (McLaws *et al.* 2023).

Because outbreaks of FMD negatively affect food security, economies, labour markets and livelihoods, all countries require emergency-response plans supported by adequate resources. This does not appear to currently be a priority for implementation by several GMS countries. These countries currently have inadequate detection and response capabilities for TADs and this also applies to OH threats, both endemic and those that may appear as EIDs. The focus of OH activities in the GMS has generally been on zoonoses, although more recently, attention to AMR and discussion of antimicrobial use (AMU) has been increasing. Zoonotic food-borne diseases, mostly presenting with acute gastrointestinal symptoms, especially from campylobacteriosis associated with poultry products, remain problematic in many areas of SEA (Nguyen *et al.* 2017). The common occurrences of these disorders most probably reflects the slow transition away from unrefrigerated and unhygienic 'wet market' animal slaughtering, processing and sale of meat products, although these processes are improving in more intensive urban areas.

Zoonoses of concern in the GMS include rabies, zoonotic influenza (e.g. HPAI, especially with recent media reports of cross-species transmissiom to cattle), anthrax, Japanese B encephalitis, cysticercosis (Larkins *et al.* 2023) and trichinosis (Suwansrinon *et al.* 2007). Preliminary serological evidence for zoonotic leptospirosis (Olmo *et al.* 2019), coxiellosis and brucellosis (Burns *et al.* 2018) and potentially fasciolosis and other fluke infestations (Sripa *et al.* 2021) indicate that further studies are required for problem definition and policy development on zoonotic disease management. Tuberculosis is also of concern, although transmission is more often between humans. A recent outbreak of bovine anthrax with human spillover affecting at least 54 people in Laos (Visapra 2024) has led to evaluation of new diagnostics and further policy considerations (J. R. Young, pers. comm.).

Despite a global effort and support for vaccination through international programs, including the Australian-funded 'Stop trans-boundary animal diseases and zoonoses (STANDZ) initiative' (Department of Foreign Affairs and Trade (DFAT) 2014), rabies persists in the GMS region. Cambodia has one of the highest rates of rabies in the world, at an estimated 800 human deaths per annum, although these estimates rely on passive surveillance reporting of dog to human bites and human case data (Baron *et al.* 2019). As has previously been observed with FMD reporting, a majority of reported rabies cases and bite injuries are from the vicinity of Phnom Penh,

where the data-collection agencies are located, so under-reporting of rural cases of both FMD and rabies is very likely. More accurate modelling using spatial Poisson regression with a Bayesian framework has been suggested to provide more accurate estimates of the number of human cases in Cambodia and assist decisions on resource allocation and control strategies for rabies (Baron *et al.* 2019).

Similarly, AMR inflicts significant mortality, morbidity and economic loss in the 11 countries in the WHO Southeast Asia region (SEAR), with all countries having developed National Action Plans on AMR that are aligned with the Global Action Plan (Sihombing *et al.* 2023). The quadripartite organizations (FAO, United Nations Environment Programme (UNEP), WHO and WOAH) developed the OH Joint Plan of Action from 2022 to 2026, proposing a set of activities, policy, legislative advice and technical assistance, to help set national targets and priorities across the sectors for the development and implementation of OH (Food and Agriculture Organisation, United Nations Environment Programme, World Health Organisation, World Organisation for Animal Health (FAO, UNEP, WHO, WOAH) 2022), and to provide support for low- and middle-income countries to strengthen OH approaches to pandemic prevention, preparedness and response, including recognising AMR as a silent pandemic (World Health Organization (WHO) 2022). Because SEAR countries endure multiple threats to AMR, a strategy of multisectoral, multidisciplinary and multi-institutional efforts has been promulgated to address AMR. This OH approach aims to connect human, animal and environmental sectors and their personnel, although success in achieving this appears to have been limited. Several SEAR countries, including Bangladesh, India, Indonesia, Nepal, Sri Lanka and Thailand, have observed trends of increasing drug resistance, despite heightened awareness and actions, with progress on AMR and OH in general considered to be fragmented. With low technical capacity and resources, a weak regulatory framework, and slow behavioural changes at all levels of the value chain in developing shared antimicrobial stewardship, effective application of several interventions in animal-production systems that can minimise the impacts of AMR are yet to be delivered (Sihombing *et al.* 2023).

A concern to both managing AMR and improving disease surveillance and response capacity in smallholder livestock systems for EIDs has been the dependence on community animal-health workers (CAHW), mostly with only rudimentary training, for delivery of therapeutics (MacPhillamy *et al.* 2021; Sieng *et al.* 2022). In the GMS, studies of village animal-health worker (VAWH) practices in Cambodia identified that many are no longer active, incomes are poor, few are women, and most operate at minimal levels of effectiveness for surveillance, with few incentives for continuing their work. Their current dependence on persistent use of routine antibiotic cover for viral diseases is of concern. With repeated incursions of TADs and increasing emergence of AMR, the VAHW system needs to be revitalised. Training to improve their contributions to disease surveillance and AMR stewardship is necessary, at least during the transition period, until trained veterinary graduates can perform these roles (MacPhillamy *et al.* 2021; Sieng *et al.* 2022).

Suggestions for a CAHW services model contributing to a modernised food system, include the following: disease prevention and biosecurity, with whole of village FMD and HS vaccination, regular endoparasite control, delivery of local quarantine; provision of reproductive services with artificial breeding, pregnancy diagnosis with welfare-appropriate surgical husbandry for castration and dehorning; and, increasingly, nutritional services, including enabling forage plantation management and molasses blocks advisory services, potentially for carbon-credit transactions for bovine methane abatement. Of these, programs that re-focus the CAHW role towards disease prevention rather than treatment, is critical for improved OH outcomes (MacPhillamy *et al.* 2021; Sieng *et al.* 2022).

Applying the lessons learned on TADs, biosecurity and FMD vaccination from SEACFMD

Ongoing project alignment with WOAH and FAO TAD/OH/EH priorities is essential in the GMS. Although there are WOAH global eradication plans for rabies, tuberculosis, PPR, ASF and FMD (World Organisation for Animal Health (WOAH) 2023*b*), FMD has been the priority disease that has been targeted to build more effective global disease-surveillance and -control capacities. FMD has been observed, and remains endemic, in SEA for ~150 years, with generally piecemeal control measures until an integrated approach was initiated by WOAH (as Office International des Epizooties, OIE) in 1990 that led to development of the SEAFMD campaign. The first regional meeting was held in 1997 and this initiative was strengthened by the launch of the global framework for the progressive control of transboundary animal diseases (GF-TADs) in 2004, aimed at global prevention, detection, and control of TADs, addressing regional and global dimensions, and combining the strengths of the international organisations to achieve agreed common objectives. Expansion of the original seven countries to 12 as the SEACFMD campaign has increased regional alliances in TAD control to collaboratively build capacities of the member countries, now within the global FMD control strategy that was endorsed by representatives from over 100 countries and international and regional partners at the 2nd Global Conference on FMD in Bangkok, Thailand, in 2012. SEACFMD and GF-TADs aim to reduce the regional and global burdens of FMD and the risks of reintroduction of the disease into free areas, assisting FMD-free countries to maintain their status.

The SEACFMD campaign facilitates a plethora of activities described in the strategic plans that have become a series of phased roadmap documents, now using tools that appear to have lifted the momentum of FMD control, including (1) the progressive control pathway for FMD (PCP-FMD) developed

by FAO and European Commission for the Control of Foot-and-Mouth Disease (EuFMD) and further endorsed by the OIE, guiding endemic countries through a series of incremental steps to better manage FMD risks, and (2) the OIE performance of veterinary services pathway (PVS) to evaluate the national veterinary services of each country to assist with achieving compliance with OIE quality standards. Both tools have been important in (1) enabling a comparative step-by-step approach in the PCP to progressively increase control of FMD through their national FMD control plans, and (2) regular conduct of a PVS audit to illuminate the deficits and record improvements in veterinary services. Currently, Laos is on PCP 2 and Cambodia on PCP 1, with neighbouring and near countries all having a higher status, with the exception of Indonesia.

There has been substantial progress through the development of the SEACFMD campaign and completion of the following five phases of implementation from 1997 to 2020: Phase 1 (1997–2001), establishing the campaign; Phase 2 (2001–2005), refining strategic direction and components of the campaign; Phase 3 (2006–2010), improving coordination and partnership efforts; Phase 4 (2011–2015), implementation and refining of FMD control strategies with targeted vaccination and enhanced technical coordination; Phase 5 (2016–2020), continuing a sustainable approach to FMD control with expansion of the PCP-FMD; and Phase 6 (2021–2025), proposing a pragmatic and sustainable approach for FMD control and prevention to guide countries in implementation of their national FMD plan on scientific evidence (World Organisation for Animal Health (WOAH) 2023*c*). Phase 6 also sought an evaluation of the SEACFMD campaign to provide guidance for its future by identifying successes and gaps, conducted in 2022. Unfortunately, shortly after we commenced the evaluation, Indonesia became infected with FMD, after a period of disease freedom of nearly 40 years.

Despite the loss of FMD-free status maintained for almost 40 years in Indonesia, the SEACFMD evaluation of almost 100 SEACFMD participants surveyed found many and varied strengths and gaps identified in the program, as detailed in documents, responses to survey questionnaires and in focus-group discussions, with recommendations offered to address the gaps. Importantly, there was general agreement that the structural expansion of SEAFMD through SEACFMD to involve more of the countries in the region beyond the GMS was appropriate. Further, as increasing interconnectedness of FMD virus pools is occurring, this adaptability should continue. There was agreement that the evolution of the phases of the SEACFMD campaign was a robust mechanism that facilitated progress, particularly since the introduction of the PVS and PCP-FMD tools. This agreement was reached despite repeated incursions of FMD, ASF, LSD, PPR, HPAI and other TADs into the region in recent years. The respondents from all roles and affiliation categories unequivocally agreed that the SEACFMD campaign has been extremely successful in progressing relationships among technical staff, facilitating fruitful coordination and communication among member countries. However, successes in nurturing political and financial commitments for sustainability of the interventions was considered insufficient (P. Windsor and H. Tiwari, unpubl. data).

There is now an increasing literature available on FMD control in SEA, including in-country history of FMD (Nampanya *et al.* 2018), virology and immunology (Buckle *et al.* 2021), epidemiology (Miller *et al.* 2018), socio-economic impacts (Nampanya *et al.* 2014*c*; Young *et al.* 2016; Wada *et al.* 2022), vaccination strategies (Rast *et al.* 2010; Nampanya *et al.* 2018; Blacksell *et al.* 2019; Xaydalasouk *et al.* 2021; Han *et al.* 2022), biosecurity (Young *et al.* 2015), and strategic disease control (Windsor *et al.* 2011), with the regional history of FMD in SEA prior to the recent FMD epidemic in Indonesia, documented in considerable detail (Blacksell *et al.* 2019). The literature has increasingly emphasised that a more effective FMD control requires the development of improved regional biosecurity and reduced 'informal' movement of livestock and their products throughout the GMS. The persistence of illegal livestock movements indicts the failure of regulatory process to effectively improve regional biosecurity. Protection of livestock and trade in animal products means complete dependence on increasing FMD vaccination, albeit with limited success in some countries.

Research on FMD has focused on vaccine serotypes and matching, strategies and efficacy, although delivery logistics and capacities are critical. Important logistical lessons were learned during delivery of an extensive FMD vaccination program between 2012 and 2016 in northern Laos, which is of relevance to future FMD vaccination programs to ensure the momentum of FMD control with vaccination is sustainable (Nampanya *et al.* 2018). The SEACFMD evaluation also provided confirmation of ongoing issues that can assist in setting of future priorities, including insufficient biosecurity with unregulated animal movements, difficulties of vaccine resourcing and delivery, inadequate funding of technical services with poor disease surveillance, low-level engagement of smallholders in disease control, deficient national emergency disease-response capacities, difficulties in co-ordination of international programs, urgent need for funding of TAD/OH/EH control in endemically infected countries (P. Windsor and H. Tiwari, unpubl. data).

Prioritising a sustainable food-security system by all stakeholders is urgently required

The outcomes of the many R&D livestock projects in Laos and Cambodia have indicated that there is a clear and present, if not urgent, requirement to greatly upscale livestock husbandry and health knowledge, attitudes, practices and infrastructure to enable a more sustainable food-security system to flourish in the GMS. This requires international

advocacy to encourage and support national governance, enabling increased investment in and facilitation of cross-sectoral collaborations that can address TAD/OH/EH concerns. This includes the inevitable requirement to divert funding priorities that enable support for the adoption of dietary and health initiatives to urgently both diminish AMR risks and, potentially, reduce EI by methane abatement in inefficient livestock production systems. Two examples of new initiatives that can facilitate this process are presented below. The first comprises a major livestock development project designed to attempt to address most, if not all the, deficits in the animal-foods value chain. The second describes a new private-sector commercial initiative to address GHGe from livestock that offers numerous leveraging opportunities to address the many other deficits in the value chain.

1. *Implementing the 'Cross-border livestock health and value chains improvement project' (CLHVCIP)*
   Although this project was designed through the difficult years of covid-19, it has finally commenced the procurement phase. This is an ambitious project that is potentially transformational because it addresses the urgent need for investments in underfunded government livestock services and recognises that the smallholder food system needs far better TAD/OH/EH management in Cambodia (ADB 2022). Whether a CLHVCIP designed for Laos will proceed is uncertain; the equivalent project for Myanmar was abandoned.
   The Cambodian project will aim to reduce TADs, food-safety and zoonotic-disease risks and strengthen livestock value chains through investments in infrastructure, capacity building and policy support. Expected outcomes include improved health, value chains, and formal trade in livestock and their products, aligned with a vision for the GMS to be a leading supplier of safe and environmentally friendly agriculture products. Expected outputs are summarised here to provide an insight into the broad scope of the project, include the following:
   Output 1: infrastrucure. Livestock health and value-chain infrastructure will be expanded and upgraded in a climate-friendly manner, including establishing disease-control zones (DCZs), comprising feedlots, quarantine facilities, laboratories, health inspection and vaccination facilities in priority border areas between Cambodia and Vietnam. This will also address critical infrastructure gaps in livestock health systems and value chains by developing breeding and waste-management facilities, slaughtering, processing, and cold-storage facilities, and marketing infrastructure. Gender-responsive and integrated climate-change mitigation and adaptation measures will be financed, with improved laboratories, and zoonotic disease and AMR control facilities. Operations and maintenance plans for infrastructure, involving smallholders, will be developed.
   Output 2: technical capacity. Strengthening production and health capacities of government staff in numerous areas will include animal-health services and extension, disease risk analysis and communication, field epidemiology, early detection, and hazard monitoring, laboratory business plans, protocols, and accreditation, TADs, safety, and AMR risk management, emergency preparedness and responses, traceability systems, livestock and meat inspection, operation of feedlots and quarantine facilities, and cold-chain management for vaccination efficacy. A gender-responsive information-communication technology (ICT)-based platform for preventing livestock epidemics and an e-traceability system will be piloted, including ICT-driven livestock identification system (LITS) supporting production and health services, a mobile-phone animal-production and -health information system (APHIS), and an improved laboratory information-management system (LIMS) with ISO 17025.
   Output 3: policies. Enabling policies for better supply, health, safety, and trade in livestock and livestock products, will provide gender-responsive policy support for effectively integrating smallholders and promoting women's roles in livestock production and value addition, recognising equivalence and harmonisation of quality and safety systems in the GMS to support formalisation of trade in livestock and their products, incentivising e-traceability systems, and mobilising private sector investments, including DCZs, feedlots, and processing facilities.
2. *Enabling private-sector investment for improved nutrition and GHGe responsiveness*
   A multi-intervention livestock development strategy involving a combination of nutritional and health interventions was proposed as a 'scale-out' strategy to assist smallholder large-ruminant livestock-farming efficiency in developing countries, with potential applications in developed countries (AgCoTech Global 2023; Windsor 2023). The strategy involves provision of high-quality molasses blocks, redesigned as 'emission-control' blocks (ECB) that provide a pathway for reducing the carbon footprint of the livestock agrifood system (Food and Agriculture Organisation (FAO) 2007, 2023*b*). The approach provides considerable increases in animal performance through improved rumen digestion efficiency, reducing EI, with inclusion of compounds that provide direct abatement of methane and aligning directly to the aspirations of the the global methane pledge (Global Methane Pledge (GMP) 2021).
   The use of high-quality ECBs may be a simple motivator for rural communities to increase the efficiency of large-ruminant production, improving rural livelihoods, food security, and, potentially, reducing GHGe from ruminants. The socioeconomic benefits provide improved community resilience in poor rural communities, in addition to

potentially enabling the global livestock sector to reduce GHGe by as much as 30% and assisting to diminish the risks of the impending climate-change catastrophe. Importantly, use of molasses blocks reduces morbidity from parasitism (Windsor and Hill 2022) and improves achievement of sustainable development goals (SDG). A range of approaches to achieve GHGe-mitigation potential have been documented and include the following: improving feeding practices and digestibility of diets; improving yields through genetics, feeding practices and animal health, and overall management; reducing land-use change arising from feed crop cultivation and pasture expansion; improving manure management and reducing the use of uncovered liquid manure management, particularly in dairy systems; and improving the efficiency of feed crop production, particularly improving fertilisation management (Opio *et al.* 2013). The use of ECBs on farm enables an ongoing dialogue with farmers on consideration of these additional approaches to improved farming practices.

The recent development of ECBs suggests that there is significant potential for leveraging this intervention to improve delivery of animal-health interventions other than the endoparasite-control approach that initiated the strategy. Livestock health is integral to food-system sustainability because the impacts of morbidity and mortality can be profound, increasing the EI (kg CO_2eq/kg product) of production with reduced meat and milk yields (MMY). A recent study found that that reducing the prevalence or eliminating diseases that have negative impacts on MMY reduces the EI of production, although the magnitude of specific disease effects varies according to the degree of output losses, disease prevalence and the characteristics of the baseline population (Capper 2023). Controlling or eliminating diseases of global importance via a culture of continuous improvement, including data collection, recording and benchmarking disease impacts, is vital. Quantification of disease impacts and communication of this to stakeholders enables evidence-based decisions throughout the value chain, including at the farm, processor, retailer and policy levels. Of note, reducing FMD in beef cattle from 45% to 5% prevalence was estimated to reduce GHGe EI by 9.11% (Capper 2023). Of interest is that the strategy of introducing molasses blocks to Laos was initiated as a means of efficiently delivering anthelmintics on farms with no cattle-holding facilities and poor uptake of endoparasite control (Rast *et al.* 2014, 2017). The work was initially directed at control of *Toxocara vitulorum* in calves with fenbendazole blocks (Olmo *et al.* 2019), and *Fasciola gigantica* control in adults with triclabendazole blocks (Business Partnership Platform (BPP) 2019; Windsor *et al.* 2020). Success encouraged the use of urea blocks in beef cattle for dry-season feeding (Windsor *et al.* 2021*b*) and in dairy buffalo for increased milk yields (Windsor *et al.* 2021*a*). The improved productivity through nutrition and health from these blocks encouraged examination of the impacts on EI and the calculation that each 20 kg block reduces EI by 470 kg CO_2eq (Windsor and Hill 2022). It is currently considered that inclusion of GHGe-reducing agents in the ECB reduces EIs via direct abatement of methane in the rumen, with the additional impact of providing GHGe abatement in the vicinity of ~800 kg CO_2eq per block (J. Hill and P. Windsor, unpubl. data).

Feedback from farmers using ECBs is that this intervention is very highly valued. Farmers describe improved productivity, animal appearance and values, with declarations that the blocks greatly assisted the management of their animals. In the larger herds, cattle and buffalo return from grazing in the fields and forests more readily to seek access to the blocks and farmers regularly commented that their animals were calmer, fatter, shinier and much more valuable (Mekong Livestock Research and Beyond (MLRB) 2023). These findings encouraged the development of a molasses-block manufacturing facility in northern Laos near Luang Prabang, which opened in April 2023 and is now producing ~3000 blocks per month. The ECBs are distributed free to farmers in exchange for the verified carbon credits accrued (Windsor and Hill 2022), with over 45 villages having received >11,500 ECBs between 1 July 2023 and February 2024. It is estimated that the plant will contribute ~150,000 ECBs in 2024, with a likely minimum abatement contribution of between 75,000 and 100,000 t of CO2eq.

This success, although preliminary, is likely to increase the motivations of farmers to adopt 'risk management', including appropriate disease preventive vaccines and therapies, plus potentially adopt biosecurity and welfare interventions. A 'whole of village' strategy to accompany distribution of ECBs has been proposed. It includes a field audit of production and a disease-risk assessment, enabling issues to be addressed that could compromise performance of the ECBs. The following questions are explored and extension advice provided, where required:

1. Are farmers able to protect the blocks from extreme weather (e.g. heavy rain)? Note that components could leach into solution on the block surface (e.g. a problem if urea is added) or fungi may grow if blocks are left in water.
2. Inventory is important for measuring consumption rates, including answering questions such as what are the numbers of dry cows, lactating cows, suckling calves, weaned calves, young cattle and bulls, that will have access to the blocks, and how many days does the block last.
3. The blocks should be delivered in association with government staff to assist the extension process on use of blocks and address other extension information and services required, e.g. disease prevention (vaccines,

biosecurity), reporting, therapies used, and what additional extension training and materials are required.

4. Have all the cattle and/or buffalo receiving blocks been vaccinated with HS and FMD vaccine within the last 9 months? If not, it may be necessary to gain agreement from farmers on the use of HS and FMD vaccination for all animals with access to the blocks.
5. Is there a *Fasciola gigantica* problem in the village because this is commonly recognised in northern Laos and can severely compromise production efficiency (Rast *et al.* 2017). It may simply be a question of asking the VVW (paraveterinarian) or village chief: 'are there 'leaves' found in the livers of slaughtered cattle and/or buffalo in this village, i.e. adult parasitic flukes of *Fasciola gigantica*?' If uncertain, then suggest collection of faecal samples from 10 animals for 'sedimentation' egg counts conducted at the local government veterinary laboratory (e.g. in Luang Prabang). If *F. gigantica* is identified, there may be a need to ask the farmers whether they agree to use the anthelmintic triclabendazole (TBZ) delivered as either an oral dose (if restraint facilities available) or in a TBZ block (at 10 mg/kg) for a 2-week period?
6. Is there a toxocariasis problem in the village, a common cause of high calf mortality and morbidity in northern Laos (Rast *et al.* 2014; Olmo *et al.* 2020)? Farmers may see worms in faeces, or faecal samples from affected calves can be collected and tested by 'flotation' egg counts conducted at the local government veterinary laboratory (e.g. in Luang Prabang). It is recommended that calves are routinely treated with pyrantel tablets within the first 3 weeks of life to eliminate roundworms (*Toxocara gigantica*), although this practice is often not performed as it should be in most villages. Because our surveys found roundworms in 70% of villages, if treatment is not being given routinely, it may be necessary to ask farmers whether they agree to use of the anthelmintic pyrantel as tablets for oral administration to young calves, or alternatively, the use of a fenbendazole (FBZ) block (at 5 mg/kg) to deliver FBZ to the cow and calf for a 4-week period.
7. Are forages being grown in the village? Most cattle and buffalo are underfed through the region and farmers are encouraged to plant forages to provide a longer-term solution to production needs, with advice on establishing plantations and animal feeding, especially promotion of the necessity of feeding forage at 10% of animal bodyweight for maintenance and at 15% for production.
8. Are farmers willing to provide information on the impact of using blocks and any other interventions (as above) that have been introduced, including socio-economic data? For evidence of impacts on SDGs, recording of changes in animal behaviour, appearance, sale value, growth rates, calf survival and reproductive performance, plus increases in livestock inventory, household incomes or changes in gender responsibility, particularly as women or children are now working more with cattle, is required.

Discussion

This paper has provided a perspective on progressing TAD/OH/EH in the smallholder livestock farming system in the GMS and more broadly in SEA. It confirmed that the concepts and practices of improved animal production, health and welfare have been slow to gain traction, despite rapidly improving economies in the region that has created a sustained increase in demand for livestock and their products. The surging demand has increased both TAD, EID and OH risks from extended informal movements of livestock and their products. There has been slow adoption of OH concepts and practices, with increased AMR risk from unregulated antimicrobial use and minimal AMR stewardship. Further, EID risks from substandard slaughtering facilities and unhygienic 'wet markets' where the sale of wildlife adjacent to livestock is often still tolerated, persists. Changed management efforts are required to improve regional biosecurity, yet motivating governments and farmers and others in the value chain to adopt these interventions, is very challenging (Young *et al.* 2015).

The use of highly visible interventions capable of creating rapid system change by motivated farmers and other stakeholders and that overcome resistance to change, are urgently required. Access to ECBs to increase productivity and improve management, accompanied by leveraging targeted health surveillance and preventive strategies, including vaccination and endoparasite control to reduce disease risk, have the potential to help drive these practice changes. It has been suggested that the apparent awakening to the importance of biosecurity in the post-covid pandemic era may convince many that TAD/OH/EH should be a collaborative priority for all medical, veterinary and animal-production authorities (Windsor and Hill 2022). There is a desperate need to create a more receptive environment for the change management required to progress both animal health and welfare through productivity innovations, assisting GHGe mitigation from the currently inefficient livestock systems, particularly in developing countries in the GMS and beyond.

The reflections documented here suggest that international development projects are important because they can contribute significantly through upscaling livestock husbandry and health knowledge, practices and infrastructure, addressing weaknesses in the value chain and creating a more sustainable food-security system. However, the multiple benefits of leveraging from commercial investments in climate-smart livestock systems is an interesting new development in Laos, and potentially Cambodia, Indonesia and beyond. This

initiative requires governance, advocacy and policy settings that encourage both cross-sectoral collaborations and reputable international trading systems, particularly for carbon credits. However, because it provides a pathway for adoption of improved livestock dietary and health initiatives that reduce high levels of methane EI and potentially diminish TAD/OH/EH risks in the smallholder production systems in the GMS and beyond, it should be encouraged and facilitated.

Currently, SEA farming systems are dominated by the inefficient smallholder 'animal-keeper' system, compromising low-level literacy, very limited resource availability and an historical preference for unhygienic 'wet-market' processing and trading that avoids refrigeration and, often, food safety and quality assurance. Further, the ineffective development of local and regional biosecurity and other disease-prevention services by under-funded national and international livestock services persists, with any improvements being only slowly adopted, particularly in the GMS. That these and other risk factors have persisted for decades, despite evidence of a sustained period of rapidly expanding regional demand for animal-sourced foods, is frustrating.

The increasing risks of TAD incursions and OH and EH concerns are clearly evident from recent disease-surveillance information. Regular arrival of new strains of FMD in SEA has accompanied persistent circulation of endemic strains, with loss of general population immunity following the inevitable replacement by vulnerable animals. Similarly, there have been repeated occurrences of HPAI, accompanied by arrival of epidemics of ASF, porcine reproductive and respiratory syndrome (PRRS), LSD and PPR in SEA and beyond. That the covid pandemic emerged in the vicinity of SEA reflects that these factors are of relevance to managing OH concerns, including EIDs, zoonoses and increasing AMR. Further, the slow adaption to increasingly deleterious climate impacts is apparent in countries where increasingly severe floods, droughts, hyperthermia and hypothermia episodes are emerging, albeit in countries with some of the highest EIs of ruminant animal production. The observations reviewed here indicate the severity of these issues in the near neighbourhood of Australia. The importance of both maintaining vigilant national biosecurity and increasing engagement with the GMS and beyond to more directly address regional TAD/OH/EH challenges, is emphasised.

References

ADB (2022) Cambodia: Greater Mekong Subregion cross-border livestock health and value chains improvement project. Asian Development Bank. Available at https://www.adb.org/projects/53240-003/main

AgCoTech Global (2023) Reducing smallholder farmer poverty. Fighting Climate Change. Available at https://agcotechglobal.com [Verified 20 December 2023]

Australian Centre for International Agricultural Research (ACIAR) (2012) Animal biosecurity in the Mekong: future directions for research and development. In 'Proceedings of a workshop held in Siem Reap, Cambodia, 10–13 August 2010. ACIAR Proceedings No. 137'. (Eds LB Adams, GD Gray, G Murray). (Australian Centre for International Agricultural Research: Canberra, ACT, Australia) Available at http://aciar.gov.au/publication/pr137

Australian Centre for International Agricultural Research (ACIAR) (2013) Cattle health, production and trade in Cambodia. In 'Proceedings from three ACIAR-funded projects presented at an international workshop held in Phnom Penh, Cambodia, 7–8 June 2011. ACIAR Proceedings No. 138'. (Eds JR Young, L Rast, S Suon, PA Windsor). (Australian Centre for International Agricultural Research: Canberra, ACT, Australia) Available at http://aciar.gov.au/publication/pr138

Baron JN, Chevalier V, Ly S, Dussart P, Fontenille D, Martínez-López B (2019) Updated estimation of the burden of rabies in dogs and humans in Cambodia using Spatial Bayesian regression modelling. *Frontiers in Veterinary Science*. Conference Abstract: GeoVet 2019. Novel spatio-temporal approaches in the era of Big Data. doi:10.3389/conf.fvets.2019.05.00032

Blacksell SD, Siengsanan- Lamont J, Kamolsiripichaiporn S, Gleeson LJ, Windsor PA (2019). A history of FMD research and control programmes in Southeast Asia: lessons from the past informing the future. *Epidemiology and Infection* **147**, e171, 1–13. doi:10.1017/S0950268819000578

Buckle K, Bueno R, McFadden A, van Andel M, Spence R, Hamill C, Roe W, Vallee E, Castillo-Alcala F, Abila R, Verin B, Purevsuren B, Sutar A, Win HH, Thiha M, Lwin KO, Khounsy S, Phonthasy S, Souriya V, Keokhamphet C, Arzt J, Ludi A, Mioulet V (2021) Detection of foot-and-mouth disease virus in the absence of clinical disease in cattle and Buffalo in South East Asia. *Frontiers in Veterinary Science* **8**, 691308. doi:10.3389/fvets.2021.691308

Burns RJL, Douangngeun B, Theppangna W, Khounsy S, Mukaka M, Selleck P, Hansson E, Wegner MD, Windsor PA, Blacksell SD (2018) Serosurveillance of Coxiellosis (Q-fever) and Brucellosis in goats in selected provinces of Lao People's Democratic Republic. *PLOS Neglected Tropical Diseases* **12**, e0006411, doi:10.1371/journal.pntd.0006411

Burns RJL, Douangngeun B, Theppangna W, Mukaka M, Wegner MD, Windsor PA, Blacksell SD (2019) Peste des Petits Ruminants (PPR) virus serological surveillance in goats in Lao PDR: Issues for disease eradication in a low-resource disease-free setting. *Transboundary and Emerging Diseases* **66**, 939–947. doi:10.1111/tbed.13109

Bush RD, Young JR, Suon S, Ngim MS, Windsor PA (2014*a*) Forage growing as an incentive to improve smallholder beef production in Cambodia. *Animal Production Science* **54**, 1620–1624. doi:10.1071/AN14136

Bush RD, Page B, Macdonald T, Young JR, Nampanya S, Suon S, Khounsy S, Henry LA, Thomson PC, Windsor PA (2014*b*) Target feeding for improved smallholder beef production in the Mekong region: lessons from Cambodia and Lao PDR. *Animal Production Science* **54**, 1219–1223. doi:10.1071/AN14133

Business Partnership Platform (BPP) (2019) Business partnership platform project: enhancing livelihoods of smallholder farmers in Laos project. Available at https://thebpp.com.au/partnership/enhancing-livelihoods-of-smallholder-farmers-in-laos [Verified 20 December 2023]

Capper JL (2023) The impact of controlling diseases of significant global importance on greenhouse gas emissions from livestock production. *One Health Outlook* **5**, 17. doi:10.1186/s42522-023-00089-y

Department of Foreign Affairs and Trade (DFAT) (2014) Independent mid-term review of the stop trans-boundary animal diseases and zoonoses (STANDZ) initiative. Available at https://www.dfat.gov.au/sites/default/files/stop-transboundary-animal-disease-zoonoses-standz-mid-term-report-2014.pdf

Food and Agriculture Organisation (FAO) (2007) 'Feed supplementation blocks. FAO animal production and health paper 164.' (Eds HPS Makkar, M Sanchez, AW Speedy). (FAO: Rome, Italy) Available at https://www.fao.org/3/a0242e/a0242e00.pdf [Verified 20 December 2023]

Food and Agriculture Organisation (FAO) (2018) 'World livestock: transforming the livestock sector through the sustainable development goals.' (FAO: Rome, Italy) Available at https://doi.org/10.4060/ca1201en [Verified 20 December 2023]

Food and Agriculture Organisation (FAO) (2023*a*) 'World food and agriculture – statistical yearbook 2023.' (FAO: Rome, Italy) Available at https://doi.org/10.4060/cc8166en [Verified 20 December 2023]

Food and Agriculture Organisation (FAO) (2023*b*) 'Pathways towards lower emissions – a global assessment of the greenhouse gas

emissions and mitigation options from livestock agrifood systems.' (FAO: Rome, Italy) Available at https://doi.org/10.4060/cc9029en [Verified 20 December 2023]
Food and Agriculture Organisation, United Nations Environment Programme, World Health Organisation, World Organisation for Animal Health (FAO, UNEP, WHO, WOAH) (2022) Global plan of action on One Health. Towards a more comprehensive One Health, approach to global health threats at the human–animal–environment interface. (FAO, UNEP, WHO, WOAH: Rome, Italy) Available at https://doi.org/10.4060/cc2289en [Verified 23 April 2024]
Global Methane Pledge (GMP) (2021) Global Methane Pledge. Available at https://www.globalmethanepledge.org [Verified 20 December 2023]
Han J-H, Subharat S, Wada M, Vink D, Phiri BJ, Sutar A, Abila R, Khounsy S, Heuer C (2022) Impact of risk-based partial vaccination on clinical incidence and seroprevalence of foot and mouth disease in Lao PDR. *Transboundary and Emerging Diseases* **69**, e309–e321. doi:10.1111/tbed.14299
Kawasaki M, Young JR, Suon S, Bush RD, Windsor PA (2015) The socioeconomic impacts of clinically diagnosed haemorrhagic septicaemia on smallholder large ruminant farmers in Cambodia. *Transboundary and Emerging Diseases* **62**, 535–548. doi:10.1111/tbed.12174
Khounsy S, Nampanya S, Inthavong P, Yang M, Khamboungheung B, Avery M, Bush R, Rast L, Windsor PA (2012) Significant mortality of large ruminants due to hypothermia in northern and central Lao PDR. *Tropical Animal Health and Production* **44**, 835–842. doi:10.1007/s11250-011-9975-1
Laos Buffalo Dairy (LBD) (2023) Laos Buffalo Dairy. Available at http://www.laosbuffalodairy.com
Larkins A, Keatley S, Insisiengmay B, Phetsouvanh R, Bruce M, Ash A (2023) The challenges of detecting *Taenia solium* and neurocysticercosis in low and middle-income countries: a scoping review of Lao People's Democratic Republic. *Tropical Medicine & International Health* **28**, 344–356. doi:10.1111/tmi.13870
MacPhillamy IBJ, Young JR, Vitou S, Chanphalleap H, Sothoeoun S, Windsor PA, Toribio J-AML, Bush RD (2021) Can improving animal health and biosecurity knowledge of para-veterinarians in Cambodia assist in addressing challenges in smallholder livestock farming? *Transboundary and Emerging Diseases* **69**, 559–569. doi:10.1111/tbed.14020
Matsumoto N, Siengsanan-Lamont J, Halasa T, Young JR, Ward MP, Douangngeun B, Theppangna W, Khounsy S, Toribio J-ALML, Bush RD, Blacksell SD (2021) The impact of African swine fever virus on smallholder village pig production: an outbreak investigation in Lao PDR. *Transboundary and Emerging Diseases* **68**, 2897–2908. doi:10.1111/tbed.14193
McLaws M, Ahmadi BV, Condoleo R, Limon G, Kamata A, Arshed M, Rozstalnyy A, Rosso F, Dhingra M (2023) 'Risk of foot-and-mouth disease SAT2 introduction and spread in countries in the Near East and West Eurasia – FAO Qualitative Risk Assessment.' (FAO: Rome, Italy) doi:10.4060/cc8173en
Miller CAJ, Young JR, Nampanya S, Khounsy S, Singanallur NB, Vosloo W, Abila R, Hamilton SA, Bush RD, Windsor PA (2018) Risk factors for emergence of exotic foot-and-mouth disease O/ME-SA/Ind-2001d on smallholder farms in the Greater Mekong Subregion. *Preventive Veterinary Medicine* **159**, 115–122, doi:10.1016/j.prevetmed.2018.09.007
Mekong Livestock Research and Beyond (MLRB) (2018) Our children now go to university. Improving rural livelihoods through livestock developments in Cambodia. Available at https://mekonglivestock.wordpress.com/2018/08/26/our-children-now-go-to-university-improving-rural-livelihoods-through-livestock-developments-in-cambodia/
Mekong Livestock Research and Beyond (MLRB) (2019) A seat at the table. Gender studies and farmer focus group discussions in Lao PDR. Available at https://mekonglivestock.wordpress.com/2019/06/12/a-seat-at-the-table-gender-studies-and-farmer-focus-group-discussions-in-lao-pdr/
Mekong Livestock Research and Beyond (MLRB) (2023) Molasses block factory opened in Laos. Available at https://mekonglivestock.wordpress.com/2023/05/08/molasses-block-factory-opened-in-laos/
Nampanya S, Suon S, Rast L, Windsor PA (2012) Improvement in smallholder farmer knowledge of cattle production, health and biosecurity in southern Cambodia between 2008 and 2010. *Transboundary and Emerging Diseases* **59**, 117–127. doi:10.1111/j.1865-1682.2011.01247.x
Nampanya S, Khounsy S, Rast L, Young JR, Bush RD, Windsor PA (2014*a*) Progressing smallholder large-ruminant productivity to reduce rural poverty and address food security in upland northern Lao PDR. *Animal Production Science* **54**, 899–907. doi:10.1071/AN13180
Nampanya S, Young J, Bush R, Windsor PA, Khounsy S (2014*b*) The food security challenge for the buffalo meat industry: perspectives from Lao PDR. *Journal of Buffalo Science* **3**, 38–47. doi:10.6000/1927-520X.2014.03.02.2
Nampanya S, Khounsy S, Abila R, Dy C, Windsor PA (2014*c*) Household financial status and gender perspectives in determining the financial impact of foot and mouth disease in Lao PDR. *Transboundary and Emerging Diseases* **63**, 398–407, doi:10.1111/tbed.12281
Nampanya S, Khounsy S, Young JR, Napasirth V, Bush RD, Windsor PA (2017) Smallholder large ruminant health and production in Lao PDR: challenges and opportunities for improving domestic and regional beef supply. *Animal Production Science* **57**, 1001–1006. doi:10.1071/AN16023
Nampanya S, Khounsy S, Abila R, Windsor PA (2018) Implementing large Foot and Mouth Disease vaccination programmes for smallholder farmers: lessons from Lao PDR, *Epidemiology and Infection*. **146**, 2086–2095. doi:10.1017/S0950268818002443
Nguyen NH, Nguyen TNM, Hotzel H, El Adawy H, Nguyen AQ, Tran HT, Le MTH, Tomaso H, Neubauer H, Hafez HM (2017) Thermophilic *Campylobacter* – neglected foodborne pathogens in Cambodia, Laos and Vietnam. *Gastroenterol Hepatology* **8**, 00279. doi:10.15406/ghoa.2017.08.00279
Olmo L, Reichel MP, Nampanya S, Khounsy S, Wahl LC, Clark BA, Thomson PC, Windsor PA, Bush RD (2019) Risk factors for *Neospora caninum*, bovine viral diarrhoea virus, and *Leptospira interrogans* serovar Hardjo infection in smallholder cattle and buffalo in Lao PDR. *PLoS ONE* **14**, e0220335. doi:10.1371/journal.pone.0220335
Olmo L, Nampanya S, Nemanic TS, Selwood N, Khounsy S, Young JR, Thomson PC, Bush RD, Windsor PA (2020) Can fenbendazole-medicated molasses blocks control *Toxocara vitulorum* in smallholder cattle and buffalo calves in developing countries? Studies from upland Lao PDR. *Animal Production Science* **60**, 2031–2043. doi:10.1071/AN19248
Opio C, Gerber P, Mottet A, Falcucci A, Tempio G, MacLeod M, Vellinga T, Henderson B, Steinfeld H. (2013) 'Greenhouse gas emissions from ruminant supply chains – a global life cycle assessment.' (Food and Agriculture Organization of the United Nations (FAO): Rome, Italy)
Pfeiffer DU, Otte MJ, Roland-Holst D, Zilberman D (2013) A one health perspective on HPAI H5N1 in the Greater Mekong sub-region. *Comparative Immunology, Microbiology and Infectious Diseases* **36**, 309–319. doi:10.1016/j.cimid.2012.11.005
Rast L, Windsor PA, Khounsy S (2010) Limiting the impacts of foot and mouth disease in large ruminants in northern Lao People's Democratic Republic by vaccination: a case study. *Transboundary and Emerging Diseases* **57**, 147–153. doi:10.1111/j.1865-1682.2010.01099.x
Rast L, Toribio J-ALML, Dhand NK, Khounsy S, Windsor PA (2014) Why are simple control options for *Toxocara vitulorum* not being implemented by cattle and buffalo smallholder farmers in South-East Asia? *Preventive Veterinary Medicine* **113**, 211–218. doi:10.1016/j.prevetmed.2013.10.021
Rast L, Nampanya S, Toribio J-ALML, Khounsy S, Windsor PA (2017) *Fasciola gigantica* infection in large ruminants in northern Laos: smallholder knowledge and practices. *Animal Production Science* **57**, 141–146. doi:10.1071/AN141032
Ratyotha K, Prakobwong S, Pirataee S (2022) Lumpy skin disease: a newly emerging disease in Southeast Asia. *Veterinary World* **15**, 2764–2771. doi:10.14202/vetworld.2022.2764-2771
Ritchie H (2021) Smallholders produce one-third of the world's food, less than half of what many headlines claim. Published online at OurWorldInData.org. Available at https://ourworldindata.org/smallholder-food-production [Verified 20 December 2023]
Ryoo S, Lee HJ, Lim D-R, Lee J-W, Bunnary S, Tum S, Lee DS, Hwang H, Jeong SG, Nah JJ, Ku BK, Kim J-M, Cha S-H (2021) Identification of the O/ME-SA/Ind-2001e sublineage of foot-and-mouth disease virus

in Cambodia. *Frontiers in Veterinary Science* **8**, 749966. doi:10.3389/fvets.2021.749966
Sieng S, Patrick IW, Windsor PA, Walkden-Brown SW, Kerr J, Sen S, Sar C, Smith RGB, Kong R (2022) Contributions of village animal health workers to foot-and-mouth disease control in Cambodia. *Transboundary and Emerging Diseases* **69**, e406–e422. doi:10.1111/tbed.14317
Sihombing B, Bhatia R, Srivastava R, Aditama TY, Laxminarayan R, Rijal S (2023) Response to antimicrobial resistance in South-East Asia Region. *The Lancet Regional Health – Southeast Asia* **18**, 100306. doi:10.1016/j.lansea.2023.100306
Sripa B, Suwannatrai AT, Sayasone S, Do DT, Khieu V, Yang Y (2021) Current status of human liver fluke infections in the Greater Mekong Subregion. *Acta Tropica* **224**, 106133. doi:10.1016/j.actatropica.2021.106133
Suwansrinon K, Wilde H, Burford B, Hanvesakul R, Sitprija V (2007) Human trichinellosis from Laos. *Journal of Travel Medicine* **14**, 274–277. doi:10.1111/j.1708-8305.2007.00136.x
Visapra P (2024) Thailand on high alert. *The Laotian Times*. Available at https://laotiantimes.com/2024/03/29/thailand-on-high-alert-for-anthrax-following-outbreak-in-laos/
Wada M, Subharat S, Sutar A, Abila R, Khounsy S, Heuer C (2022) Socioeconomic impacts of clinical foot-and-mouth disease and a risk-based partial vaccination campaign for smallholders in Lao People's Democratic Republic. *Transboundary and Emerging Diseases* **69**, e1825–e1838. doi:10.1111/tbed.14517
Windsor PA (2011) Perspectives on Australian Animal Health Aid Projects in South-East Asia. *Transboundary and Emerging Diseases* **58**, 375–386. doi:10.1111/j.1865-1682.2011.01216.x
Windsor PA (2023) Multiple benefits of molasses nutrient blocks for cattle: helping the fight against climate change. Available at https://researchoutreach.org/articles/multiple-benefits-molasses-nutrient-blocks-cattle-helping-fight-climate-change/ [Verified 23 April 2024]
Windsor PA, Hill J (2022) Provision of high-quality molasses blocks to improve productivity and address greenhouse gas emissions from smallholder cattle and buffalo: studies from Lao PDR. *Animals* **12**, 3319. doi:10.3390/ani12233319
Windsor PA, Freeman PG, Abila R, Benigno C, Verin B, Nim V, Cameron A (2011) Control and eradication of foot and mouth disease in the Bicol surveillance buffer zone in the Philippines. *Transboundary and Emerging Diseases* **58**, 421–433. doi:10.1111/j.1865-1682.2011.01225.x
Windsor P, Khounsy S, Earp F, MacPhillamy I, Young J, Bush R (2020) Managing welfare and antimicrobial-resistance issues in treating foot-and-mouth disease lesions: a new therapeutic approach. *Veterinary Medicine: Research and Reports* **11**, 99–107. doi:10.2147/VMRR.S273788
Windsor P, Martin S, Khounsy S, Young J, Thomson P, Bush R (2021*a*) Improved milk production from supplementation of swamp buffalo with molasses nutrient blocks containing 10% urea. *Dairy* **2**, 90–103. doi:10.3390/dairy2010009
Windsor PA, Nampanya S, Olmo L, Khounsy S, Phengsavanh P, Bush RD (2021*b*) Provision of urea-molasses blocks to improve smallholder cattle weight gain during the late dry season in tropical developing countries: studies from Lao PDR. *Animal Production Science* **61**, 503–513. doi:10.1071/AN20517
World Health Organization (WHO) (2017) One Health. Available at https://www.who.int/news-room/questions-and-answers/item/one-health [Verified 20 December 2023]
World Health Organization (WHO) (2018) Nipah virus. Available at https://www.who.int/news-room/fact-sheets/detail/nipah-virus [Verified 20 December 2023]
World Health Organization (WHO) (2022) One Health in G20 countries. WHO SEARO, New Delhi. Available at https://www.who.int/news/item/23-12-2022-one-health-in-g20-countries#:~:text=Both the OH Joint Plan,fallout seen with COVID-19 [Verified 23 April 2024]
World Health Organization (WHO) (2023) Severe Acute Respiratory Syndrome (SARS). Available at https://www.who.int/health-topics/severe-acute-respiratory-syndrome#tab=tab_1 [Verified 20 December 2023]
World Organisation for Animal Health (WOAH) (2023*a*) Avian Influenza. Available at https://www.woah.org/en/disease/avian-influenza/ [Verified 20 December 2023]
World Organisation for Animal Health (WOAH) (2023*b*) Global strategies for the control and/or eradication of animal diseases. Available at https://www.woah.org/en/what-we-do/global-initiatives/disease-eradication/ [Verified 20 December 2023]
World Organisation for Animal Health (WOAH) (2023*c*) SEACFMD Roadmap 2021–2025. Available at https://asean.org/wp-content/uploads/2021/12/FAFD-36.-SEACFMD-Roadmap-2021-2025.pdfn [Verified 20 December 2023]
Xaydalasouk K, Innoula N, Putthana V, Chanthavongsa K, Snoeck CJ, Hübschen JM, Oudomphone P, Chan B, Muller CP, Black AP, Pommasichan S, Pauly M (2021) High seroprevalence of Foot and Mouth Disease in Laos: call for nationwide vaccination campaigns and disease surveillance. *Transboundary and Emerging Diseases* **68**, 2345–2352. doi:10.1111/tbed.13895
Young JR, O'Reilly RA, Ashley K, Suon S, Leoung IV, Windsor PA, Bush RD (2014) Impacts on rural livelihoods in cambodia following adoption of best practice health and husbandry interventions by smallholder cattle farmers. *Transboundary and Emerging Diseases* **61**, 11–24. doi:10.1111/tbed.12193
Young JR, Evans-Kocinski S, Bush RD, Windsor PA (2015) Improving smallholder farmer biosecurity in the Mekong region through change management. *Transboundary and Emerging Diseases* **62**, 491–504. doi:10.1111/tbed.12181
Young JR, Suon S, Rast L, Nampanya S, Windsor PA, Bush RD (2016) Benefit-cost analysis of foot and mouth disease control in large ruminants in Cambodia. *Transboundary and Emerging Diseases* **63**, 508–522, doi:10.1111/tbed.12292

Data availability. The majority of the data used in this review is available in the cited references, and where additional information is provided, data supporting the perspectives offered, can be made available by contacting the author.

Conflicts of interest. The author has received project funding from many sources over many years, including provision of consulting services to WOAH, FAO, ADB, Animal Ethics Pty Ltd and AgCoTech Global. However, none of these agencies and companies had any influence over decisions involved in presenting this perspectives review. The author is a Guest Editor of the SAADC 2023 special issue of *Animal Production Science*. To mitigate this potential conflicts of interest, they were blinded from the review process.

Declaration of funding. Many projects from a range of funding agencies contributed historically to the work in this review, although none had any role in decisions on the current presentations of the work described.

Acknowledgements. This work reflects the efforts of a vast range of collaborators working closely with MLRB, some continuously, since 1998. Their efforts, generosity and camaraderie are most sincerely appreciated.

Author affiliation
[A]The University of Sydney, Sydney School of Veterinary Science, Camden, NSW 2570, Australia.