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List of papers

Paper I – Halloran A., Vantomme P., Hanboonsong Y., Ekesi S. 2015. Regulating entomophagy: the challenge of addressing food security, nature conservation, and the erosion of traditional food culture, *Food Security*, 7 (3): 739-746.

Paper II – Halloran, A., Roos, N., Eilenberg, J., Cerutti, A., Bruun, S. 2016. Life cycle assessment of edible insects for food protein: A review. *Agronomy for Sustainable Development*, 36: 57.

Paper III – Halloran, A., Roos, N., Hanboonsong., Bruun, S. 2017. Life cycle assessment of cricket farming in north-eastern Thailand. *Journal of Cleaner Production*. 156: 83-94.

Paper IV – Halloran A., Roos N., Hanboonsong Y. 2017. Cricket farming as a livelihood strategy in Thailand. *Geographical Journal*, 183 (1): 112–124.

Paper V – Halloran, A., Oloo, J., Ochieng Konyole, S., Ayieko, M., Roos, N. Awareness and adoption of cricket farming in Kenya. Submitted to *World Development*.

Related work

The publications below are not included in the PhD thesis:

- Halloran A, Roos N, Flore R, Hanboonsong Y. (2016) The development of the edible cricket industry in Thailand. *Journal for Insects as Food and Feed*, 2 (2): 91-100.
- Halloran A, Münke C, Vantomme P, Reade B, Evans J. (2015) Broadening insect gastronomy. *Sustainable Food, Beverage & Gastronomy*, Routledge.
- Evans J, Alemu M, Flore R, Frøst M, Halloran A, et al. (2015) 'Entomophagy': an evolving terminology in need of review. *Journal for Insects as Food and Feed*, 1 (4): 293-305.
- Halloran A, Flore R, & Mercier C. (2015) Notes from the 'Insects in a Gastronomic Context' workshop in Bangkok, Thailand. *Journal for Insects as Food and Feed*, 1 (3): 1-4.
- Halloran A, Münke C, Vantomme P, van Huis A. (2014) Insects in the human food chain: global status and opportunities, *Food Chain*, 4 (2): 103-118.

Together with Nanna Roos, Paul Vantomme and Roberto Flore, I also took on the role as editor for a textbook:

- Halloran A, Roos N, Flore R, Vantomme P (Eds.) (Autumn 2017). *Edible insects in sustainable food systems*. Springer Nature Academic Press.

Oral and poster presentations related to the dissemination of the results of my PhD research can be found in Appendix A.

Summary in English

Background

Over the past five years, a growing amount of attention has been placed on the potential of edible insect species to address the global challenge of food and nutrition security. Even greater attention has been put on the handful of insect species which can be easily domesticated and raised *en masse*. Some of these species belong to the Gryllidae (cricket) family. The oldest and most developed example of cricket farming for human consumption comes from Thailand. For nearly 20 years, thousands of rural Thai farmers have adopted and developed these unique farming systems, providing not only food for their households but also employment and income. This development has resulted in the subsequent promotion of small- and medium-scale insect farming systems in rural communities in low- and middle-income countries (LMICs), such as Kenya. However, the policy environment for cricket farming, the social and environmental impacts in Thailand and the adoption of cricket farming in Kenya is not well understood. There is therefore a critical need for more research into the impacts of cricket farming on nutrition, rural livelihoods and the environment. My thesis addresses this research gap by reviewing the literature and empirically examining cases from Thailand and Kenya. The results of this thesis are a part of ‘GREEiNSECT: Insects for Green Economy’, a research project that assesses the contribution of insects to green economy.

Methods

The thesis is presented in the form of five research papers. Paper I is presented in the form of case studies, where the policy and legislation governing the consumption and production/harvest of edible insects in four countries (Kenya, Thailand, Switzerland and Canada) are compared and contrasted. Paper II is a literature review of the previously published life cycle assessments that have been conducted on insects for food and feed. Empirical data collected in Thailand and Kenya in 2014 and 2015 are presented in Papers III, IV and V. Paper III uses life cycle assessment technique to evaluate the environmental impacts associated with current and future cricket production in contrast with broiler chicken production in Thailand. Paper IV employs questionnaires to assess the contribution of cricket farming to rural livelihoods in northern and north-eastern Thailand. Data from this study was used to inform the development of the household questionnaires used in Paper V, a study of the awareness and adoption of cricket farming amongst

cricket farmers and households in Homa Bay, Kisumu, and Siaya counties, Kenya. Thirteen focus group discussions were also conducted in the same counties.

Results

The results of the case studies in Paper I showed that there is a lack of policies, regulations, and legislation governing global insect consumption by humans. In the countries where insects have been a part of traditional diets (Thailand and Kenya), edible insects have not yet been a significant part of well-designed policies concerning health, nutrition, agriculture, food safety, and conservation.

In Paper II, a total of six life cycle assessment (LCA) studies were found to have been carried out in Europe. Each LCA had unique goals and scope, functional units, and impact categories. Future LCAs are recommended to address existing gaps in knowledge, such as quantifying greenhouse gas emissions from farmed insect species.

In Paper III, a LCA was carried out to compare the environmental impacts of commercial cricket farming and broiler chicken farming. The LCA found that commercial cricket farming has fewer environmental impacts when compared to medium-scale broiler chicken production in the same region of Thailand. A future scenario that modelled a contained, climate-controlled cricket production facility demonstrated further resource efficiency and lower environmental impacts. A major hotspot in cricket production was found to be related to the production of feed that contains maize meal and soy meal.

In Thailand, results from a study (Paper IV) of 49 cricket farms in three provinces found that farmers took up cricket farming to diversify their existing agricultural livelihood strategies and provide significant income to rural households. Social and human capital also played a role in the adoption and perpetuation of cricket farming and helped farmers negotiate market access. Overall, cricket farming had a positive impact on rural livelihoods in Thailand.

In Paper V, 42 cricket farmers and 317 farmers who have not adopted cricket farming were interviewed. A number of variables influenced the awareness and adoption of cricket farming in Kenya, including distance from a cricket farm, crop diversity score, and frequency of visits to the extension office. Results from focus group discussions show that lack of adequate equipment, space and housing were most frequently cited as barriers to the adoption of cricket farming.

Dissatisfaction with the lack of market for crickets and lack of training were cited as the second and third most common barriers.

Conclusion

The results of this thesis show that there is limited policy and legislation that specifically addresses the production/harvest and consumption of crickets or other insect species. There are limited LCAs of insect farming and limited data on the environmental impacts associated with insect farming systems. Further, cricket production was found to have a lower environmental impact than broiler chicken production. Cricket farming had a notable impact on rural livelihoods in Thailand in terms of household income, and social and human capital. Finally, cricket farming is a livelihood strategy that few farmers in Kenya are aware of. The barriers to adoption must be addressed if cricket farming is to have a positive impact on food and nutrition security. The findings presented in this thesis have relevance for non-governmental organizations, civil society, policy makers, intergovernmental organizations and governmental agencies seeking to implement policies and interventions to improve access to a nutritional source of food with a relatively low environmental impact that can also improve rural livelihoods.

Dansk resumé

Baggrund

I gennem de seneste fem år er interessen for potentialet af spiselige insekter til at løse den globale udfordring omkring mad og ernæringsikkerhed øget støt. Der har specielt været fokus på den gruppe af insektarter, der let kan opdrættes og masseproduceres. En af disse arter er Gryllidae familien (fårekylinger), og en af de ældste og mest udviklede eksempler på domestificeret fårekylingeproduktion findes i Thailand. I næsten 20 år har tusindvis af thailandske landmænd opbygget og udviklet et landbrugssystem omkring fårekylingeproduktionen, som udover at levere mad til husholdningsbehov også har forbedret deres beskæftigelses- og indkomstmuligheder. Med inspiration i denne thailandske succeshistorie er interessen steget for at promovere små og mellemstore insektopdrætssystemer i andre lav- og mellemindekomstlande (LMIC), som for eksempel Kenya. Det politiske miljø for fårekylingeproduktion, de sociale- og miljømæssige konsekvenser i Thailand og potentialet for- og tilpasningen af fårekylingeproduktion i Kenya, er dog ikke udbredt. Der er derfor et umiddelbart behov for mere forskning i fårekylingeproduktionens betydning for ernæring, for livet på landet og for miljøet. Denne afhandling adresserer den manglende forskning ved brug af en litteraturgennemgang og gennem en empirisk undersøgelse af to cases i Thailand og Kenya. I denne PhD afhandling undersøger jeg virkningerne af fårekylingeproduktionssystemer i forhold til levevilkår, ernæring og miljø i landdistrikter i det nordlige Thailand og Kenya. Afhandlingen bidrager til forskningsprojektet 'GREEiNSECT: Insects for Green Economy', der sætter fokus på insektproduktionens rolle i den grønne økonomi.

Metode

Afhandlingen består af fem individuelle forskningsartikler, der undersøger forskellige aspekter af problemstillingen. I *artikel I* præsenteres et case-studie, der sammenligner den lovgivning og de regulativer, der styrer forbruget og produktionen af spiselige insekter i fire lande (Kenya, Thailand, Schweiz og Canada). *Artikel II* præsenterer et litteraturreview af alle tidligere publicerede livscyklusanalyser af insektproduktion som fødevarer og foder. Empiriske data indsamlet i Thailand og Kenya i 2014 og 2015 danner grundlag for analyserne i *artikel III, IV, og V*. Artikel III bruger metoder fra livscyklusanalysen til at vurdere miljøpåvirkningen af nuværende og fremtidig fårekylingeproduktion i sammenligning med slagtekyllingeproduktion i Thailand. Artikel IV bygger på en spørgeskemaundersøgelse blandt husstande på gårde i det nord- og nordøstlige

Thailand, og analyserer ud fra disse data fårekylningeproduktionens bidrag til husstandenes levevilkår. På baggrund af disse resultater udviklede vi et spørgeskema til brug i studiet præsenteret i artikel V. I denne artikel undersøges miljø- og levevilkårskonsekvenserne af fårekylningeproduktion blandt fårekylningeproducenter og husstande i amterne i Homa Bay, Kisumu og Siaya, Kenya. Fokusgruppediskussioner blev også brugt i de samme områder.

Resultater

Resultaterne fra case-studierne i artikel I viste, at der mangler politiske beslutninger, regulativer og lovgivning af sektoren for produktion af spiselige insekter. Selv i de lande hvor insekter traditionelt set har været en del af kosten (Thailand og Kenya), er spiselige insekter endnu ikke blevet inddraget i lovgivningen på områder såsom sundhed, ernæring, landbrugspolitik, fødevarerikkerhed eller miljøbeskyttelse.

Artikel II viser, at seks livscyklusanalyser på insektproduktionsområdet er gennemført i Europa. Hver livscyklusanalyse havde sine egne mål og omfang, såvel som funktionelle enheder og kategorier. Fremtidige livscyklusanalyser bør adressere huller i den eksisterende viden, såsom kvantificering af drivhusgasser fra insektproduktionen.

I Artikel III blev en livscyklusanalyse udført for at sammenligne miljøbelastningen ved hhv. fårekylningeproduktion og slagtekyllinger. Livscyklusanalysen fandt at fårekylningeproduktion har mindre miljøpåvirkning sammenlignet med en mellemstor slagtekyllingeproduktion i den samme region af Thailand. Desuden viste et fremtidsscenario, der modellerede en fårekylningeproduktion med et lukket og klimakontrolleret produktionssystem, at resourceffektiviteten kan øges og miljøpåvirkningerne reduceres yderligere. De primære miljøbelastninger i fårekylningeproduktionen er relateret til foderproduktionen, der pt. indeholder majs- og sojamel.

I Thailand fandt et studie (artikel IV) af 49 fårekylningeproduktioner i tre provinser, at landmænd indførte kommerciel fårekylningeproduktion for at afveksle deres eksisterende landbrugsproduktion og for at øge indtægten i husstande i landdistrikterne. Husstandenes sociale og kulturelle kapital spillede også en vigtig rolle for oprettelsen og fortsættelsen af fårekylningeproduktionen samt for adgangen til markedet. Samlet set har fårekylningeproduktionen haft en positiv indvirkning på husstandsøkonomien og levevilkårene blandt landmændene i Thailand.

I artikel V blev 42 fårekylningeproducenter og 317 landmænd, som endnu ikke havde optaget fårekylningeproduktion, interviewet. En række faktorer havde indflydelse på opfattelse og optag af fårekylningeproduktionen i Kenya, bl.a. afstand fra en fårekylningeproduktion, afgrødediversitets score og besøg til offentlig landbrugskonsulenttjeneste. Resultater fra fokusgruppediskussioner viste, at mangel på adgang til produktionsmidler, udstyr og plads var de hyppigst nævnte barrierer for deltagelse i fårekylningeproduktionen. Utilfredshed med mangel på et egentligt marked for fårekylninger samt mangel på oplæring blev nævnt som hhv. anden og tredje hyppigst nævnte barrierer for deltagelse.

Konklusion

Denne PhD afhandling viser, at der er begrænset politik og lovgivning, der specifikt adresserer produktionen af fårekylninger og andre insekter i de undersøgte lande. Resultaterne viser endvidere, at der er få egentlige livscyklusanalyser af insektproduktion og at data omkring miljøpåvirkningen af insektproduktionssystemer er begrænsede. Derudover vises det, at fårekylningeproduktionen har lavere miljøpåvirkning end slagtekyllingeproduktion. Fårekylningeproduktionen har haft en betydelig positiv indvirkning blandt husstande i landdistrikter i Thailand i form af øget indtægt samt social og menneskelig kapital. Endelig viser afhandlingen, at kun få landmænd i Kenya er bevidste om at fårekylningeproduktion kan være et indtægtsgrundlag. Hvis disse systemer skal udbredes yderligere med større fødevarer- og ernæringsikkerhed til følge, skal barriererne for deltagelse adresseres. Resultaterne, som er præsenteret i denne afhandling, har relevans for ikke-statslige organisationer, civilsamfundet, lovgivere, mellemstatslige organisationer og statslige enheder, som ønsker at implementere lovgivning og indsatser for at forbedre adgang til en ernæringskilde med relativt lav miljøbelastning, som også kan forbedre landlige husstandes indtægtsgrundlag.

1. Introduction

A growing amount of attention is being placed on the potential of edible insect species to address food and nutrition security (1,2). Even greater attention is being directed towards the handful of insect species that can be easily domesticated and raised *en masse*. Globally, the oldest and most developed example of cricket farming for human consumption comes from Thailand. For nearly 20 years, thousands of rural Thais have adopted and developed these unique farming systems, providing not only food for their households but also employment and income (3–5). This development has resulted in the subsequent promotion of cricket farming systems in rural communities in low- and middle-income countries (LMICs) such as Kenya.

In Kenya, different kinds of insects such as ants, termites, crickets and lake flies have been consumed by various ethnic populations (6–10). Activities supporting the development of cricket farming systems have occurred in the Lake Victoria region of Kenya since 2012 (11). The ubiquity of malnutrition and food insecurity has been a motivating force to explore the potential of increasing insect consumption in Kenyan households (12).

At the same time, the dire need to shift towards more environmentally sustainable diets has highlighted edible insects as a potential alternative to traditional livestock such as cattle and swine (1,13,14). Physiological and biological differences between insect species and other conventional livestock species mean that insects do not use their metabolism to maintain body temperature, and, therefore, use resources more efficiently (13).

While the potential benefits of cricket farming to nutrition, livelihoods, and the environment are becoming increasingly known to a wide range of actors, the dynamics of these systems are still understudied. Thus, an enhanced understanding of the value chain, legislation and regulations, impacts on rural economy, and possible improvements in production methods and techniques is required. Moreover, investigation of the linkages between agriculture and nutrition is essential for the creation of more socially, environmental, economically and culturally sustainable food systems.

1.2 Objectives of the PhD thesis

The main objective of this thesis is to assess the impact of cricket farming on rural livelihoods, nutrition, and the environment in rural Thailand and Kenya. The specific objectives of this thesis are:

1. To conduct four cases studies in Thailand, Kenya, Switzerland, and Canada on the actions that have been taken or are underway to develop the various multi-jurisdictional regulations and legislation governing the farming, collection, and consumption of insects (Paper I)
2. To review studies on the life cycle assessment of edible insect production systems and to develop a reference framework for future life cycle assessments on edible insects (Paper II)
3. To perform a life cycle assessment of cricket farming in north-eastern Thailand in relation to broiler chicken farming (Paper II)
4. To conduct a preliminary assessment of cricket farming as a livelihood strategy in north-eastern and northern Thailand (Paper IV)
5. To evaluate the determinants and barriers to the adoption of cricket farming in rural Kenya (Paper V)