Expert Meeting On "Innovative Control Approaches Of Rodent-Borne Epidemic Diseases And Other Public Health Consequences Of Rodents' Proliferation"

MEETING REPORT

20 – 21 March 2019
Lima, Peru

World Health Organization

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Executive Summary

The Expert Meeting on "Innovative control approaches of rodent-borne epidemic diseases and other public health consequences of rodents' proliferation" was organized by the World Health Organization (WHO HQ) and the Pan American Health Organization/World Health Organization (PAHO/WHO) with support of the Peruvian Ministry of Health and the United Kingdom Department for International Development (DFID). This first-ever scientific meeting took place from 20 March to 21 March 2019 at the PAHO/WHO Country Office in Lima, Peru with the objective of holding a kick off meeting for a new and novel, international and inter-sectoral initiative that would advocate and develop innovative prevention and control strategies to mitigate rodents' impacts on human health.

Forty-five international experts from 21 countries as well as representatives from the Food and Agriculture Organization (FAO), Institute Pasteur (Paris and Madagascar), WHO HQ, WHO Regional Office of South-East Asia (SEARO), PAHO and the Peruvian Ministry of Health attended the expert meeting. The attendees brought a diversity of expertise in microbiology, public health, medicine, ecology, agriculture and shared their experiences as researchers, practitioners, and policy makers. The PAHO/WHO representative to Peru – Dr. Raul Montero – made welcome remarks and the General Director of the Peru National Center of Epidemiology, Prevention, and Control of Diseases of the Ministry of Health – Dr. Gladys Marina Ramirez Prada – opened the meeting. The methods of work included key note presentations, expert panel discussions, working groups, and group discussions with a focus on intersectoral approaches for a roadmap that will support the initiative.

Prior to the meeting, a working document with the baseline of the roadmap was shared with all the participants. Over the course of the two-day meeting, participants reviewed the multifaceted impact of rodents on human health, agreed on key technical principles related to rodent control and prevention with regards to human health, and identified opportunities for leveraging efforts with the agriculture, food and nutrition security, community development, and livelihood improvement programmes. Priorities for research and development, capacity building, and investment case were also discussed and are now being summarized in the roadmap.

Across the board, participants agreed that a multisectoral approach that reaches all levels (local, regional, national, and global), and takes into account, the interactions between health, climate, food systems, environment, and society (including socio-economic factors, cultural and religious aspects, population structure and growth, and conflict) is needed for rodent control programs. The lack of monitoring and evaluation components in most programs was highlighted as the reason for why the efficacy of most control programs are not known. Participants also discussed the lack of cost-benefit studies related to rodent control and its impact on human health, food production etc., which made donor advocacy work difficult. To address some of the needs identified, participants agreed on the need for a literature review of currently available rodent control methods and any evidence generated from related studies; cost-benefit analyses of the social and economic impact of rodent borne epidemics that can be used for advocacy; standardized indicators

to measure rodent impact on various sectors; and a gold standard for long term efficacy testing of rodent control programs.

Major meeting action points were as follows:

- PAHO/WHO will write and share the workshop report
- WHO HQ will write reference article to be published in "The Weekly Epidemiological Record" (WER)
    - Scientific committee will write a concept paper to be published in a peer-review journal, which will then be used as a reference paper for securing funds for the initiative
    - Scientific committee, PAHO/WHO and WHO/HQ to complete the roadmap.

Background

Rodents have been a known public health threat for centuries and are emblematic of poverty, underdevelopment, and epidemics. In recent years the world has witnessed outbreaks of unexpected magnitude such as plague in Madagascar (2000+ cases, 200+ deaths during August to December 2017), Lassa fever in Nigeria (2000+ cases with a case fatality rate of 25% during January to April 2018), increasing numbers of hantavirus cases in the Americas (6000+ in the past 10 years), and leptospirosis cases associated with floods and extreme weather events in countries ranging from Peru to Indonesia (1 million cases/year, 60,000 deaths/year).

All these diseases, and others such as typhus, toxoplasmosis, babesiosis, Lyme disease and leishmaniasis involve at certain stage of their cycle, the presence of rodents as reservoirs, intermediate hosts, or direct vectors. We can estimate that 400 million human cases of rodent related zoonoses occur every year. However, the impact on global health goes beyond these infectious diseases. Accidents, injuries, and degraded living conditions can also be added to this toll. In addition to lessening the morbidity and mortality associated with rodents, improved rodent control could enhance food and nutrition security for the more than 280 million undernourished people worldwide.

Despite rodents representing a global health threat, no global approach has been developed for their control. For other vector-borne diseases, vector management, notably mosquito control, has been one of the pillars in the public health response. Such a comprehensive approach to rodent-borne disease control has not yet been thoroughly developed, though we argue that it would be a strategic tool to prevent the spread of deadly epidemic diseases with case-fatality rates ranging up to 60%, which is far higher than observed with any arboviral diseases. No international organization has attempted to tackle this important international public health topic so far, despite the fact that this question is at the crossroads of several key sectors such as infectious disease emergency response, nutrition, One Health, and International Health Regulations.

Even worse is the lack of consensus and current inability to provide with the appropriate technical expertise on rodent control, especially in emergency context. WHO's last guidelines were issued in the 1990s and the last meeting of a WHO scientific group on this subject is dated back to 1974 (WHO Technical report series No.553). There is an urgent need for the international community to address this question by setting up an international and inter-sectoral initiative which will:

- Advocate and technically assist Integrated Pest Management programs.
- Guide and coordinate operational research.
- Develop targeted prevention and control strategies for rodents and their ectoparasites.
- Improve prevention and control strategies for the rodent-borne diseases with the highest public health impact.

General Objective

To hold a kick off meeting for a new and novel, international and inter-sectoral initiative that will advocate and develop innovative prevention and control strategies to mitigate rodents' impacts on human health.

Specific Objectives

- Identify key actors and stakeholders among the community of researchers, rodent control specialists, public health practitioners, and policy makers.
- Initiate the design of a roadmap that will support the initiative, and specifically identify priorities for Research & Development, Capacity Building, and Investment Case.
- Agree on selected technical principles related to rodent control and prevention / human health (rodent borne diseases particularly) and identify opportunities for leveraging with initiatives (e.g. FAO, IRRI, etc.) in agriculture, food & nutrition security, community development and livelihood improvement programmes.

Method

The expert meeting was conducted employing several interactive and participatory methodologies, including:

- Key note presentations on specific topics
- Expert Panel Discussions
- Experience sharing to foster better understanding and exchange ideas
- Poster presentations from their respective field of work
- Results based group work – world café format – to agree on key technical principles and next steps for the roadmap

Participants

Forty-five international experts from 21 countries as well as representatives from the Food and Agriculture Organization (FAO), Institute Pasteur (Paris and Madagascar), WHO HQ, WHO Regional Office of South-East Asia (SEARO), PAHO and the Peruvian Ministry of Health attended the expert meeting. The attendees brought a diversity of expertise in microbiology, public health, medicine, ecology, agriculture and shared their experiences as researchers, practitioners, and policy makers.

The full list of participants and facilitators who attended is available in Appendix II.

Summary of Meeting

Day One: 20 March 2019

Opening Remarks

Dr. Raul Montero – PAHO/WHO Representative to Peru – welcomed the participants to the expert meeting in Lima and highlighted the fact that despite the numerous strategies in existence, there still isn't a specific policy for rodent control in place. He emphasized the need for a multi-sectorial approach involving ministries of health, agriculture, and other relevant sectors, and implementing control at the local level by working together with municipalities. Dr. Montero encouraged participants to hold discussions on ways to plan research and innovation as there is a need to generate evidence for the control of these diseases. Finally, before wishing the participants a productive meeting, Dr. Montero also shared Peru's experience with leptospirosis and associated risk factors such as heavy rains, floods, and poor access to healthcare and sanitation.

Dr. Sylvain Aldighieri – PAHO/WHO Health Emergencies (PHE) Deputy Director – welcomed the participants and first highlighted the significance of holding the meeting in Peru. He explained that Peru is on the frontline of battle against rodents and their impact on human health, having dealt with outbreaks of plague, leptospirosis, and hantavirus among others. Dr. Aldighieri saw the meeting as an opportunity to recognize Peru's long history of work in the field of rodent control and also for the participants to hear about Peru's field experiences. Next, Dr. Aldighieri explained how the meeting highlighted the structure of WHO with representatives from all three levels of the organization – the country office (Peru), the regional office (PAHO), and Headquarters (WHO Geneva) – and underscored the importance of working together with more partners. He also explained how WHO Geneva created Global Leptospirosis Environmental Action Network (GLEAN) which provided an action-oriented global platform for information sharing and multi-sectorial collaboration with the aim of reducing the impact of leptospirosis outbreaks. Finally, Dr. Aldighieri articulated how a large number of rodent related diseases are present in the Region of the Americas which could one day lead to a "Public Health Emergency of International Concern (PHEIC)", like Zika did in 2016.

Dr. Eric Bertherat – WHO/HQ Infectious Hazards Management (IHM) Advisor – shared that there is a lack of global perspective on rodent borne diseases and their control. He explained how after his return from the latest plague outbreak in Madagascar, he was even more convinced of the gaps in outbreak response and the need for a global strategy with regards to rodent borne diseases. Dr. Bertherat thanked Dr. Michel Jancloes, Dr. Steve Belmain, Dr. Grant Singleton and Dr. Soledad Colombe for the support they have been providing to the project, and thanked DFID who made this meeting possible. Finally, Dr. Bertherat thanked PAHO for organizing the expert meeting on such a short notice. He stressed that the meeting is the first concrete milestone of the initiative, which aims at creating a long-term momentum. Dr. Bertherat expressed hope that the meeting would serve as a starting point for a new global health adventure.

Dr. Gladys Marina Ramirez Prada – General Director of the Peru National Center of Epidemiology, Prevention, and Control of Diseases – welcomed the participants and officially opened the meeting. She shared her experiences working with rodents, first as a student enrolled in a rodent control program in Cusco, and then as a field epidemiologist working in Lima while investigating an outbreak of plague. Dr. Ramirez explained how Peru had most recently faced two outbreaks of leptospirosis in the last year due to flooding and extreme weather events. She expressed thanked all the participants for their commitment and hoped that the meeting facilitates the creation of a roadmap and eventual solutions.

Meeting Overview

PRESENTATION: Background report, meeting objectives and expected outcomes

Dr. Eric Bertherat – WHO/HQ Infectious Hazards Management (IHM).

Dr. Eric Bertherat provided the overview, scope, objective, and expected outcomes of the expert meeting. He explained how all the participants were gathered in this meeting because even though rodents represent a global health threat at the crossroads of several key sectors, there is a lack of global approach and a current inability to provide countries with the appropriate technical expertise on rodent control.

Key Points

The overarching goal of this initiative is to advocate and develop innovative prevention and control strategies to mitigate rodents' impacts on human health. Two global axes were developed for the initiative to reach this goal with the following structure:

AXIS 1: Identify what is known about the impact of rodents and successful rodent control strategies

1) Overview of the impact of rodents – what we know so far
    - Rodents and human diseases
    - Rodents and food security
    - Rodents and home-related injuries
2) What solutions for rodent control exist, which one's work, and why?
    - Recent innovations
    - Successful programs

AXIS 2: List the technical needs for improved rodent control and advocacy on a larger scale

1) Develop research on the following topics
    - Burden of rodents' infestation to be further estimated
    - Economic impact of rodents
2) Facilitate the creation of Integrated Pest Management (IPM) programs and private sector innovation
    - By reviewing all past or existing IPMs related to rodents and evaluation of their impacts
    - By reviewing the most cost-effective methods for control of rodents' ectoparasites while taking into account chemical toxicity for human populations

- By revising and updating control strategies and tools
- Via implementation studies to evaluate rodent control methods' impact on diseases incidence
- By organizing training programs
- By facilitating research networks and stakeholder engagement

3) Identify the specific needs for R&D, capacity building, and investment case
   - Identify the specific needs

Keynote Presentation

Comprehensive overview of rodent problems

Dr. Steve Belmain – Professor of Ecology. Natural Resources Institute. University of Greenwich

Dr. Belmain gave a comprehensive overview of the rodent problems starting with a brief history of rodents as humanity's oldest and most pernicious pest problem, both in the field of agriculture and diseases, as they became pests as early as agriculture was created. Dr. Belmain covered a wide range of related topics including why rodents are still a problem; their impact on agriculture, infrastructure, and infectious diseases; and the need for rodent control.

Key Points

Why are rodents still a problem?

Rodent control is still a neglected field despite its progress. Most agriculture units have entomology departments, but no rodent department.

Our own psychology and how we perceive rodents in our environment has been the main obstacle to implementing proper rodent control. Rodents are idealized (e.g. Disney mice heroes).

Humans anthropomorphize animals including rodents – we think they are like us and think how we think. Instead, we must think of what they are capable of, versus what they are not capable of.

Rodents host an incredible diversity, with more species than any other animal family. They is no one control mechanism for all and they live in different habitats, have different breeding rates, preferences, eating habits, and diets.

Rodent control is also a political issue – it attracts attention, can lead to loss of tourism, and carries this dimension of unsanitary environment and people.

Rodents are a source of food in many countries including in India and Mozambique and are often considered a delicacy and part of the local economy.

Impact on Agriculture

The increase in agriculture production means that we are unnaturally giving sources of rich food to rodents.

Images of rice crops eaten by rodents show fields entirely eaten, as if a lawn mower had been used. These losses in crops and associated malnutrition will often be associated with diseases too.

The problem is that crop damage happens not only at the beginning of the process but also towards the end. Harvests will be contaminated with feces and urine, damage will happen at the storage facilities, in factories, to the cartons, and even at final stage of processing.

Rodents will remove the seed germ of a crop, which is the most nutritious part of the food. However due to a lack of other alternatives, people will still eat what is left of it.

We understand rodents better, but there are still huge knowledge gaps, especially on the socio-economic impact of rodents on agricultural production.

Impact on Infrastructure

- Rodents will damage all kind of pipes, burrow into the foundations of houses, and when monsoon season comes, the houses collapse.
- They will also gnaw in personal items, causing holes in mosquito nets, in utensils, any type of fabric, etc.
- Very little has been described on infrastructure losses due to rodents, both in rural areas and in cities.
- Studies putting all the numbers together and quantifying the damage are needed.

Impact on Infectious Diseases

Rodents go from unclean to clean habitats (sewage to kitchen) and are very good reservoirs for many diseases. They are involved in the transmission of more than 60 diseases and none of them are funded by donor programs.

Leptospirosis is among the top 6 infectious hazards reported globally and the top 3 in the Region of the Americas – it is present all over world. Rodents are also reservoirs for murine and scrub typhus, and other rickettsia diseases.

Rodents are reservoirs for Arenaviruses in Africa. More cases of Lassa fever are being reported in Nigeria compared to previous years – however it is not clear if it is the result of increased clinical awareness, over-reporting, or truly an increase in the number of cases.

Hantavirus is another example of a rodent-borne disease – an Old-World disease which led to historic population collapses in Mexico.

The link between rodent populations and disease transmission can be complicated to understand as there is often a time delay between availability of food for rodents, modification of the rodent populations, and disease transmission.

Plague – a rodent-borne disease present all over the world – has a very complicated ecology with a cycle that is always redefined with extinction, possible reintroduction, and many factors facilitating outbreaks. More and more countries are reporting plague outbreaks, but most cases nowadays are from Africa – it has the perfect environment for plague to survive in the wild.

Rodent-borne diseases also represent a challenge in terms of clinical awareness and are often undiagnosed/misdiagnosed because the associated symptoms are very similar to arbovirus diseases like malaria and dengue.

Researchers are making progress in recognizing that diseases are often rodent borne. For example, researchers have been retroactively analyzing non-malarial fever case samples and found that most are bacterial diseases transmitted by rodents, for which antibiotics worked.

More studies are needed to quantify the loss and long-term impact of the rodent-borne diseases.

Rodents Can and Need to Be Controlled

When talking about control, the sociology of human behavior and farmers' perception is a challenge once more. For example, there are two types of poison for rodent control – acute and chronic. Since most farmers like seeing a dead body, if they use the chronic poisons, they do not think it worked and think that it was a waste of their money. Therefore, there is a need to learn how to educate people in controlling rodents efficiently.

A lot of money is allocated for agriculture and rodents research, but not for commercial agriculture. For example, a company could use 2000 kg of raticides per hectare to prevent crop damage – an extremely efficient method, but at a cost to the environment. The environmental impacts of such methods are difficult to quantify, and the cost of control is still an unknown variable.

There is still no great consensus on how to quantify the impacts of rodents – a multidisciplinary approach is needed would be the most impactful.

Example of Rat ZooMan project in Cato Crest Informal Settlement, Durban, South Africa to combat rodent borne diseases: Taylor, P. J., Arntzen, L., Hayter, M., Iles, M., Frean, J., and Belmain, S. R. (2008). *Understanding and managing sanitary risks due to rodent zoonoses in an African city: beyond the Boston Model*. Integrative zoology 3, 38–50.

Conclusion

Thus, there are opportunities as well as challenges in implementing rodent control. A lot of progress has been made with regards to rodent control in agriculture and is the proof that it is doable.

Capacity building needs to happen, but most of the work has so far been done by researchers. So, how do we do we expand the knowledge from research?

Multi-disciplinary and inter-disciplinary teams are essential for overcoming rodent pest issues.

There is a need to motivate public action by raising awareness of rodent-borne diseases because currently, most people only view food-losses as a problem caused by rodents.

Session 1: Rodent Borne Diseases and Epidemics

1.1) Presentation: Lassa Fever in Nigeria – Experience and Lessons Learned

Dr. Ayodeji Olayemi – Natural History Museum. Obafemi Awolowo University. Nigeria (presented by Dr. Herwig Leirs on behalf).

Dr. Olayemi's presentation focused on Lassa fever epidemiology in Africa, and in particular, on the experiences and lessons learned from Lassa fever outbreaks and research in Nigeria. The presentation covered everything from number of cases by year, to the molecular aspects of Lassa virus and its hosts, as well as studies conducted on the disease ecology and its implications on control in different parts of the continent.

Key Points

In Africa, Lassa fever has so far been constrained to West Africa with 100,000 to 300,000 cases occurring each year. It has been endemic for a long time in Nigeria but was not considered a problem until recently.

In Nigeria, more confirmed cases have been reported in recent years – 322 cases in 2017 (CFR 28.5%), 633 cases in 2018 (CFR 27%), and 420 cases in 2019 (Jan – Mar) with a case fatality ratio (CFR) of 25%.

A team of researchers working in Nigeria sampled 22 localities since 2011 and found that both rodents and humans were infected with Lassa fever virus (LASV). The species *Mastomys natalensis* was the most frequently infected and this species can have up to 24 babies in one litter. *Mastomys natalensis* is present all over Africa, but different subspecies mitochondrial groups can be found in different regions (https://wwwnc.cdc.gov/eid/article/22/4/15-0155_article).

Lassa virus is found both in the A-I group and the A-II, which means that Lassa virus does not have to be limited to West Africa and could spread to Central Africa.

LASV was also detected in different rodent species where they also found arenaviruses. Hence, there is concern that a wider ecological opportunity for Lassa fever to occur exists in places where currently, no human cases have been reported but where the host present has potential to carry the virus. It is possible to infect rodent species with other arenaviruses in the laboratory – they even start shedding the virus but, in the field, this occurrence is extremely rare.

Understanding the link between rodent and human populations is key to targeted rodent control. For example, studies in Guinea show that the prevalence of Lassa virus in the rodent population is much higher during the rainy season, however rats are more likely to enter houses during the dry season. As a result, human cases do not show seasonality, but the mechanisms of infection are different during the wet (highly infectious rodents but few contacts with humans) and the dry season (low infectiousness but more contacts).

However, some studies show that disease seroprevalence does not change with rodent control. Therefore, while rodent control would help in reducing population density, it does not aid in reducing seroprevalence within rodent populations. Furthermore, if rodents are infected later in their lives they recover, but if transmission happens in-utero, then they are infectious for the rest of their live.

During simulations of rodent control, researchers found that:

- If only annual rodent control is conducted (assuming no immigration from other areas): Even if 75% of the rodent population is killed, the infection will remain in rest of the population.
- If continuous rodent control is set up: The disease disappears after a few years of maintained rodent control. However, if the entire population is eliminated, then it creates a niche and stimulates recolonization facilitating the infectious rodents to return.
- If a vaccine was to be introduced: With 75% of vaccination, infection can be cleared in 4 years by creating a shield composed of immune rodents that prevent infected rodents from coming into the area/village. More information at: Plos – Rodent control to fight Lassa fever: Evaluation and lessons learned from a 4-year study in Upper Guinea.

For rodent control, it is crucial to understand their ecology. There is still a lot of work to be done to survey the natural reservoirs and their involvement in spread of diseases.

1.2) Expert Panel

Dr. Herwig Leirs, Dr. Claudia Muñoz-Zanzi, Dr. Daniel Paris, Dr. Heikki Henttonen, Dr. Soanandrasana Rahelinirina

Overarching questions

1. What are the commonalities and differences in how rodents should be controlled for different diseases?
2. How do we integrate and express chronic health impacts alongside mortality-focused data for different diseases?
3. What should be done about rodent control during/after disease outbreaks?

Key Points

Rodent Control Approaches

Rodent control options generally rely on two methods – mortality control or environmental modifications. In addition to other cultural and/or moral objections, there is a lot of contention on killing animals since it can increase the density of other species. However perhaps one of the commonalities in rodent control could be modifying the environment to make it rodent proof.

One approach could be to first stratify the associated diseases into direct rodent contact diseases (e.g. leptospirosis and hanta virus) and indirect rodent associated diseases (ectoparasites). This could be further stratified into reservoirs or parasite carriers, facilitating an upstream approach from each pathogen.

There is also a need to think about control strategies in terms of rodent control in urban areas versus semi-urban, peri-urban and agricultural settings when considering an upstream approach.

Categorizing control efforts by levels of urgency is also another possibility – An epidemic situation where the rodent population needs to be quickly reduced using targeted methods vs. permanent control efforts with traps intended to capture and kill every rodent that enters the home/field.

It might be helpful to prioritize rodent borne diseases, or at least prioritize the transmission pathways, which would alleviate programs. Then perhaps there won't be a need to understand the full ecology but only the common drivers, which would allow for disease risk assessments based on the context. However, this method does not take into account, other impacts of rodents on humans, including crop destruction.

Another approach could be charting short, medium, and long-term plans for rodent control. For example, if rodents are a recurring problem, there is a true need to investigate the mechanisms at stake. A short-term solution to address the immediate rodent problem, in parallel with a long-term plan to understand the recurring mechanisms would be the most ideal solution in this instance.

Due to the diversity of rodent borne diseases and their transmission routes, control programs will vary by diseases. Disease ecology could also be different for one disease from region to region. Therefore, one of the goals of this initiative should be to publish general guidelines on rodent-control which can then be adapted to specific local needs.

A matrix listing the already existing tools, settings and capacities for rodent control should be created so that in the context of an epidemic, the response can fit the structures already in place. In addition, efforts should be made to implement proper monitoring and evaluation of currently used rodent control strategies.

For all pathogens, the best general approach seems to be consistently keeping rodent populations down and reducing contact between humans and rodents (e.g. house proofing).

Case Studies

Environmental Control: In Peru, the best methods to combat plague were development strategies with an ecological impact at the community level (e.g. limiting access to food, construction of silos, & improving guinea pig production) and strong political will to implement proper and sustainable surveillance. After 20 years of implementing these strategies, North Peru is free of plague cases.

Disease Control: In Argentina where hanta virus has been endemic for 40 years, the following multi-prong approach was used to control the disease: (i) strong surveillance system by recording cases in the context of person, place and time (ii) improved diagnostics to increase case detection sensitivity (iii) Human vaccination. The country was able to reduce the annual number of cases from 1000 to 30 and no reported fatalities.

Multisectoral Control: In Nicaragua, while working on a leptospirosis outbreak, the engineers suggested that the pH of the soil is important to maintain infection and could extend life of the bacteria for weeks, which in turn extends the exposure to humans. This useful piece of information otherwise not known by the team on the ground at the time, highlights the need for a multisectoral approach for the control rodents and rodent borne disease.

Gaps and Challenges

Ideally, control of rodents should take into account all the different types of diseases that they carry, in addition to evaluating whether the control takes place before or during an epidemic. In practice, it is impossible to have many different research programs to understand all the different diseases associated with rodents. There is a need for concrete guidelines – even with modest amount of evidence that currently exists.

Most rodent control programs to date have been unorganized and carried out on an ad-hoc basis when it should have been systematized. Therefore, there are no formal evaluations of those control strategies and their impact on disease transmission to humans.

Data – especially collected in relation to time and space – is limited for rodent borne diseases. If the human case data had geographic and time information, researchers could capitalize on the layers of other data and information collected from the different disciplines working on the same issue (e.g. environmental and climatic data).

Rodent control before an outbreak is another topic that should be addressed. In mosquito-borne diseases, the size of mosquito population before an outbreak does not affect the outbreak at all. However, in directly transmitted rodent borne diseases, there is a threshold level of number of vectors per individual to be crossed before reducing transmission.

On the ground there needs to be strong policy advocacy and action to spread awareness of the importance of disease ecology

Other Points for Consideration

Rodent control activities and their timing should be closely assessed - control at the wrong time of the year might attract more rodents than before.

Consideration should be given to risk factors beyond what is happening in the house – for example, a farmer might in South East Asia might be more exposed on the fields than at home. In Madagascar, the problem

is the flea population and not the rodents themselves, and in Europe, more research is being conducted on climatic effects on rodent population.

Climatic factors can affect rodent fertility often causing outbreaks – while changes in the climate cannot controlled, reviewing related data might help in predicting outbreaks ahead of time.

Vaccinology of rodents is a nice solution in theory, but in practice, presents with quite a few issues, including recolonization.

Session 2: Biodiversity, International Health Regulations and Urban Settings

2.1) Presentation: Urban Rodents Diversity and Public Health – the Case of African Cities

Dr. Gauthier Dobigny – Research Institute for Development, Benin.

Dr. Dobigny presented on the diversity of urban rodents in the context of the rapidly urbanizing cities on the African continent, which is expected to have 1.2 billion city dwellers by the year 2020, of which, a large percentage will be living in slums. He also delved into the three mechanisms of biodiversity involved when it comes to rodents and infectious diseases: Spillover of pathogens, Spillback of pathogens, and the Dilution Effect. Finally, Dr. Dobigny discussed how the urban rodent diversity is poor in Africa, and how the peri-urban matrix will impact cities and their rodent diversity.

Key Points

Rodent and Pathogen Diversity in African Urban Dwellings

Different rodent species can be competent for different pathogens. Rodents includes rats, mice, and shrews, which make 1/3 of captures in cities and are a huge part of the fauna.

Urbanization is quite late in Africa but also very extensive, rapid and usually quite informal, with wide and poor urban areas. The African continent is expected to have 1.2 billion city dwellers by 2020 and a huge percentage of those will be living in slums.

Rodents have an affinity for cities, a complex landscape in the context of rodent control because there are few to no predators, and food resouces are availabe consistantly, facilitating contineous reproduction.In addition, most cities have poor sanitation with open or no sewers, thereby increasing the interactions between humans and rodents, and subsequently, the risk of zoonotic transmission. All these factors are exacerbated by a poor medical structure and low awareness which increases the risk of human to human transmission, and the possibility of epidemics as well. Lassa fever is one of those diseases often presented as rural issue currently, that could be emerging in cities.

Cities are also pivotal for trade and exchange of goods and services, and movements of people. Since they usually have important hubs of transportation (e.g. boats, trains, and cars), more invasive species can be introduced and further be disseminated inland leading to epidemics/pandemics, and spread of other genetic traits (AMR, rodenticide resistance) etc.

In many new world European and Asian cities, urban rodent communities are quite stable in terms of specific diversity (rats, mice, squirrels, etc). In Africa, it is still evolvoing and changing from town to town – for example, in Niamey, there is a complete segregation of *Rattus rattus* and *Mastomys natalensis*, but even black rats are replacing *Mastomys natalensis*. The species composition in Dakar on the other hand is becoming monospecied, with house mice invading and replacing other species in the whole city.

In summary, rodent species assembalges are varied in Africa and depend on the original landscapes, as well as city structure, geography and history. This ensures urban rodent communities which are different from one town to another, a trend which is still evolving in many African regions. Therefore, the consequences of the changing rodent communities on circulating pathogens might be an important effect to monitor.

Rodent Biodiversity and Dilution/Amplification Processes

Most studies on the effect of biodiversity on infectious diseases come from non-urban, westernized systems, and theoretical expectations are not always verified. Data on urban socio-ecosystems are almost non-existent.

There are three mechanisms of biodiversity involved in the context of rodents and infectious diseases:

(i) Spillover of pathogens from invasive to native host

(ii) Spillback of pathogens from native hosts to competent invasive hosts (hard to prove) leading to increased prevalence

(iii) Dilution effect (complex and not fully understood) – pathogens are diluted within more diversified and/or undistributed host communities. Some hosts might be amplifiers.

For each, it is important to take into account the socioeconomic and climatic context to draw conclusions.

Cities are usually infested by poorly diversified rodent communities. Furthermore, urban rodents are highly anthropophilic/generalist species which carry a wide spectrum of zoonotic pathogens and are mostly amplification hosts. This means that strong dilution effects are probably limited in urban habitants and/or should be of poor interest in terms of rodent control.

Rodent Control

Since many African urban rodent communities seem context specific, only locally-adapted control strategies might work.

However, targeted rodent control might only be useful in spatially manageable areas for some specific objectives (e.g. seaports, storehouses etc).

In large slum areas, the only realistic way to control rodent populations in the long-term maybe to advocate for integrated improvement of the urban environment.

Conclusions

- In the coming years, cities will host more house mice, and pathogens that will be able to circulate will change within the communities.
- Dilution effect is of poor interest in urban control due to the low species bio-diversity.
- To reduce contact between humans and rodents, we need to increase awareness.
- To reduce the incidence of diseases and epidemics, we need high vaccination rates and proper medical care.
- Integrated urban environmental policies, which are upstream, will allow to target everything.

2.2) Expert Panel

Dr. Thomas Bagan, Dr. Gauthier Dobigny, Dr. Herwig Leirs, Dr. Lourens Swanepoel, and Dr. Jason Tan

Overarching questions

How is maintaining biodiversity important for rodent pest regulation?

Are there ways to mitigate continued anthropogenic and climate changes affecting incidence of rodent borne diseases? Do we understand enough about such effects?

What are the main differences and similarities in approach and delivery of rodent control in urban vs. rural environments?

Key Points

How is maintaining biodiversity important for rodent pest regulation?

Biodiversity matters in rural setting, but for urban environments, it depends on the setting. In the case of agriculture, there is a need for functional biodiversity landscape, but in cities where there is no species diversity, it is impossible to take biodiversity into account for rodent control. In rural areas and outskirt of cities, dilution of diseases is extremely context dependent.

However, currently there aren't enough comprehensive studies which explores the importance of biodiversity for rodent pest regulation. Most of the current rodent control experience is in the field, where only one species is targeted and eliminated using poison indiscriminately. However, there are no formal evaluations and/or studies which researched the full impact of these control measures – both on the targeted species and others unintentionally eliminated. For example, in Africa, even though the *Mastoma* rodent species has the highest population density and therefore targeted frequently for rodent control, it is the first species to recover its population after mass poising, which calls into question, the sustainability such control methods.

There are also case-studies and anecdotal examples of when predators were removed from the environment and rodent population increased as a result. In New Zealand, it has been shown that if predators or competitors are eliminated, it has the effect of introducing new species. What is not known is whether the dilution effect is big enough to make a difference for the risk of human infection.

The impact of biodiversity by way of new species introduction was also underscored when the risk of human infection changed according to susceptibility profile of the new rodent vector. For example, in France, there were many people with Siberian chipmunk pets who released them in the forests near the cities. These chipmunks were more susceptible to *Borrelia* than the native squirrels but also competed with them in terms of habitat. Now, people in that area are more at risk of being infected with Borrelia in peri-urban forests. Therefore, introducing a new rodent can sometimes completely modify the transmission of a disease to humans. This example also highlighted the importance of peri urban habitats when considering the impact of rodents on humans – directly and indirectly.

Lastly, the question of biodiversity is perhaps most pertinent to agricultural landscapes where it is important to consider the environmental component, sometimes more than the rodent component.

Are there ways to mitigate continued anthropogenic and climate changes affecting incidence of rodent borne diseases? Do we understand enough about such effects?

Climate change seems to have an effect on rodents and rodent-borne diseases. For example, in Peru El Niño and la Niña have also been shown to have an impact on rodent diversity. El Niño affects the northern parts of the country more than the rest – subsequently an increase in rickettsiosis cases due to rodents were observed in those northern parts of Peru. El Nino has also been associated with the emergence of plague. In Europe, climate change is associated with change in the population of bank voles (*Myodes glareolus*) – hosts for Puumala hantavirus. In addition, climate change is expected to impact flea borne diseases – population of fleas goes up in dry seasons and down in wet season. This directly influences the incidence of diseases such as scrub and murine typhus in humans. Climate change might also have consequences on human behavior – warmer temperatures lead to more outdoors recreational activities, which can lead to more contact between humans, rodents and ectoparasites, which in turn can result in an increase in the incidence of associated infections. Finally, climate change creates more refugees than war, new slums and more diseases – all of which will be exacerbated by human population movements which usually follows these events.

Currently, when it comes to surveillance in the context of climate change, there are very few dedicated to its' impact on human health and diseases. Majority of the funding for climate change research goes to the environmental sectors even though, its' effects are shown to be multisectoral. Therefore, there is a need to systematically summarize the knowledge currently available on anthropogenic and climate changes affecting incidence of rodent borne diseases and evaluate areas to be updated or further researched. While we cannot prevent what has already occurred to date with climate change, we should be prepared to mitigate its' impact on health.

What are the main differences and similarities in approach and delivery of rodent control in urban vs. rural environments?

Every environmental setting is different. Leptospirosis in the Caribbean islands has a different mode of transmission than leptospirosis in African cities.

Rodent control in cities: In urban areas, it all comes down to the ability to correlate rodent data to the local structures in the city, and the proportion of rodents moving around.

In Singapore – a small and densely populated country – authorities used a four-prong approach to prevent rodent-borne diseases by keeping the rodent population below a certain level as follows:

1. *Field Surveillance* which began in 2011 provided data for heat maps of rodent proliferation allowing easier surveillance and detection of problematic proliferation. Since rodents are attracted to food, surveillance was set around shopping centers and markets. Active surveillance was conducted every 2 months (6 times a year).

2. *Rat control* was then put in place. 70% of the Singaporean population lives in government housing – 50 to 60 floors high – with a central column rubbish system, which is often full at the end of the day, harboring many rats.

3. *Laws were established* for licensing of food establishments whose license were suspended if they didn't comply. Furthermore, the establishments feared having their names broadcasted among those with unsanitary conditions.

4. *An Interagency task force* was set up with a one health network linked to the Ministry of Health.

In the Port of Cotonou, Benin, authorities set up disinfection/desterilization every 3 to 6 months to combat the rodent problem. In an attempt to use fewer chemicals, the port authorities worked with researchers and discovered three species including *Mus musculus* which is also found in Niger – perhaps hinting at an invasive species. The other species discovered was *Bartonella sp* which represented 67% of all rodents in the port. As a result, the port developed a partnership with the Research Development Institute (IRD per its acronym in French) to extend the research on rodents.

Rodent-borne disease control: Since Singapore has a low prevalence of rodent-borne diseases, authorities are able to investigate a notified case within 24 hours. However, in the general population, there was a lack of general knowledge on identifying rat infestations. Therefore, the health authorities produced brochures and pamphlets for risk communication. To aid surveillance and control in a place like Singapore – an urban city with many hard to reach and closed spaces – authorities used technological tools like motion sensors to detect rodent activity. They are also monitoring rodent resistance and other environmental factors which will then be added to model for predicting rodent population. Therefore, using tools like a risk map based on environmental risk factors, and conducting specific capacity building in local settings through the use of technology, Singapore was able to reduce the rodent population by 55% and currently, less than 5% of shopping malls have signs of rodent activities. The Singapore example highlights the importance of research and technology at different stages of rodent control, along with political will in the form of strong legislative policies which are enforced without hesitation.

Gaps and Challenges

The Singapore rodent control program encountered a number of challenges such as:

1. Rats changing behavior and colonizing entire buildings.
2. Lack of will among stakeholders due to the costs of the strategy, without directly observable benefits.
3. When integrated with other vector control programs, rodent control was overruled by dengue outbreak control programs.

Therefore, in 2015, Singapore created a team dedicated solely to rodent control.

Awareness and Funding Challenges

In countries with only a few cases of rodent borne diseases, securing funding for rodent control program can be challenging. Therefore, the case needs to be built on the potential risk of spread and the possibility of rodents becoming the source of the next emerging epidemic. It would be helpful to have a standard to facilitate that process.

When statistics are shared, they need to be presented in a way that can be contextualized and shared easily. For example, in Singapore, while they do not monitor diseases in rodents, some seroprevalences are known. Since rat infestations are a problem in restaurants, when the stakeholders were informed that 22% of the rats were carrying rickettsia and 41% had some ectoparasite infestation, it convinced them into supporting control programs beyond a Band-Aid fix.

There are no concrete studies/evidences proving that rodent control impacts transmission of human diseases.

There is no data on the importance of rodent control in food processing industries and its impact for importing countries.

Session 3: Multifaceted Impact of Rodents on Human Health and the Importance of Multi-sectoral collaboration and Engagement

3.1) Presentation: Rodents' impact on agricultural productions and public health: A One health approach

Dr. Marisa Caipo – The UN Food and Agricultural Organization (FAO). Office for Latin America and the Caribbean. Chile.

Dr. Caipo presented on the importance of a One Health approach for rodent control, given the complex and interconnected ecological relationships between health, food systems, environment, and society (including socio-economic factors, cultural and religious aspects, population structure and growth, and conflict). She explained the importance of rodent control in the context of the world's growing population, which will result in more food production, and more people living in urban areas – all of which will exacerbate the rodent population issue and associate risks. Dr. Caipo explained how in 2019, 4 out of the 5 top global risk in terms of impact are related to climate change. Other risks include biodiversity loss and ecosystem collapse, man-made environmental disasters, extreme weather events, natural disasters, water crises, food crises, failure in climate-change mitigation and adaptation of strategies – all of which is directly or indirectly related to spread of infectious diseases as well.

Key Points

General Background

By the year 2030, the global population is expected to reach 8.5 billion people and by 2050, the population will reach an estimated 9.7 billion people.

By the year 2050, 70% of the global population will live in urban areas with the number of mega cities increasing from 28 in 2014 to 41 cities in 2030.

As the world population increases, so will the need for increases in agricultural production. By the year 2025, agricultural production will need to be increased by 10%, meat production by 16%, and drinkable water access by 55%.

The world is also more interconnected now than ever. Since 2011, an increased risk for infectious diseases due to changes in landscape through climate change, water crises, etc. was observed.

One Health

One Health – a multisectoral approach that reaches different levels (local, regional, national, and global), and recognizes the interconnection between people, animals, plants and their shared environment – can be applied to several public health issues (AMR, food safety, vector control).

Since the drivers of most emerging zoonotic diseases are the same (Increased trade, antimicrobial resistance (AMR), climate change, and ecosystem degradation), they can all be addressed with a One Health approach.

One Health Approach Examples

The Tripartite agreement signed by the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the World Organization for Animal Health (OIE) to address threats at the human-animal-ecosystem interface, with a focus on antimicrobial resistance, rabies, and others. (Now includes UNEP).

The resolutions of the United Nations Convention on Biological Diversity acknowledging the value of One Health.

The Sendai Framework for Disaster Risk Reduction 2015–2030 recognizes biological hazards under its scope.

Review of approaches used by researchers and organizations can be used for decision making at policy or government level to improve human and animal health and welfare (*Quantitative Outcomes of a One Health approach to Study Global Health Challenges*. Falzon et al, 2018).

Challenges

- Data gaps.
- Lack of integrated data analyses to better understand the relevance of animal and environmental health indicators to human health.
- Lack of evidence for regulation of the possible environmental spread and persistence of substances (pharmaceuticals including antimicrobials, chemicals, pesticides, etc.) and the resulting potential short-term and longer-term effects on human health and the environment.

Agricultural Production and Rodent Control

Rodent control is important for the entire food production chain which involves interaction between the environment, agriculture, animals, humans, climate, and economics.

The cost benefit analysis for rodent control in food production is complicated and therefore rarely available. One of the reasons is because such an analysis requires integrating different systems along the production chain to determine one common denominator which can get complicated and subjective.

One research paper on the global burden of pathogens and pests on major food crops (Savary et.al, 2019) did not include rodents or bird pests – only insects. Another paper (Oerke, 2006) studied crop losses due to top pests and included rodent pests as well. Both papers approximated the burden to be 30% - more studies and data are needed.

Decision makers for any rodent control program or policy need to take into account, the interactions between health, food systems, environment, and society (including socio-economic factors, cultural and religious aspects, population structure and growth, and conflict)

Manuals for pest control including rodents are available for every step of the food production chain – however, there is a need to raise awareness of the associated risks among decision makers and secure appropriate funding.

The last FAO pest manual was published 20 years ago, and they used to have officers specialized in rodent control, but now they do pest control in grains. The last book on post-harvest operations dates back to 1999. A paper called "FAOs need for rodent ecology population dynamics and forecasting data" was published in 1977. The 1988 Rodent Pest Management was reprinted in 2018, to bring focus and research back to rodent control.

Risk Assessment

Examples of some tools (new and old) and analysis to be considered include:

- A model to predict rat infestation in WDC (Casey et al, 2018), model validation.

- Predictive analytics to combat rodents in Chicago (Thornton, 2015) capitalizing on data that could maximize efficiency and lower costs.
- Using geographic information systems for tracking an urban rodent control program (von Wahlde and Colvin, 1994).

Predictive Analytics (Predictive Modeling + Big Data) could be particularly useful for contextualizing the rodent problem and quantifying the impact on human health to policy and decision makers.

Next Steps

Rodent control is now on the radar of many countries. For example, the agricultural agency in Peru has been trying to control rodents in different parts of Ica. In the Galapagos, they first took birds away, then used mass rodenticides, and now the island is opened to tourists again. In Bolivia too, there are talks about rodent control.

So now that there is a new push on rodent control with growing interest from many countries, there is an urgent need to take advantage of this momentum. The roadmap for rodent control is crucial as it will help inform a global strategy with cross sectoral initiatives for rodent control. The strategy should include raising awareness, providing evidence for governance and good practices, and highlighting the gaps and needs in research and development for rodent control.

3.2) Expert Panel

Dr. Marisa Caipo, D. Oswaldo Cabanillas, Dr. Grant Singleton, Dr. Nyo Me Htwe, and Dr. Sudarmaji

Overarching questions

What lessons for rodent disease control can be learned from efforts to control rodents in agriculture?

How can we facilitate a multi-sectoral approach to rodent control across different stakeholders, e.g. donors, international agencies, government departments, researchers, NGOs?

How do we quantify and express the multiple effects of rodents on people's livelihoods (health, agriculture, environment, economics)?

Key Points

In agriculture, a rat is not a rat – less than 10% are pests and the other 90% play an important part in the ecological system and benefit it. However, when it comes to diseases, it is more complicated (> 2200 species).

Importance of a One Health Approach

To contextualize One Health, one can consider the phenomenon of El Niño in Peru, where with the increment of rainfall, crop production increases, providing more food for the rodents, and subsequently facilitates pullulating of rodents and plague outbreaks. Furthermore, once the harvest is depleted, rodents move from the outdoor crop fields to nearby houses in search of food. Peru tried to act on the environment for control in such instances but forgot to take the fleas into account, resulting in a plague outbreak.

Similarly, in sugar cane plantations, water availability generates more sugar cane harvest and subsequently an increase in the rodent population. When the sugar canes are burned to remove the outer leaves before

harvesting, the rodents move indoors to the houses nearby. These houses represent an area of risk and highlight that the wrong practice can generate the wrong kind of response, ecologically speaking.

What lessons for rodent disease control can be learned from efforts to control rodents in agriculture?

Based on the experience of rice crops in Asia, rodent-borne diseases outbreaks occur in areas with intensive cropping pattern and asynchronous planting time for rice. Outbreaks can also occur due to migration of rice field rat from an area with limited availability of feed during fallow years to areas with feeds. Therefore, the risk profile of rodent borne disease in humans changes based on the behavioral changes of the rats – who themselves are reacting to a change in their environment (food source). One of the recommended methods to address this issue is to adjust cropping methods and to implement the trap barrier system to catch rats when they migrate from fallow lands to areas with food.

Appearance or disappearance of new diseases are also linked to changes in agricultural practices. In both Spain and Argentina where agricultural production has been intensified, new invasive plant species have appeared.

While rodent control within agriculture systems have been mostly successful, there is a need to add monitoring and evaluation component for assessing the rodent control programs. The issue of sustainability should also be addressed.

How do we quantify and express the multiple effects of rodents on people's livelihoods (health, agriculture, environment, economics)?

Studies are only now starting to look at social benefits, effects on livelihood, and issues that have emerged from rodent control. For example, in Asia research on perceptions of economic and social benefits from rodent control are underway but there is still a big knowledge gap. A lot more research is being conducted in African countries.

How can we facilitate a multi-sectoral approach to rodent control across different stakeholders, e.g. donors, international agencies, government departments, researchers, NGOs?

Currently in most places, rodent control is responsibility shared by many sectors – for example, the Ministry of Health is responsible for mosquito control, the Ministry of Agriculture is responsible for rodent control in rural areas and the Ministry of Health in Cities, and on the farm, the Ministry of Agriculture, Department of Food Safety is responsible.

Another challenge is getting the natural resource sectors to work together with agriculture and health sectors. Therefore, raising the rodent issue at the National level is difficult and requires the coordination and cooperation of different sectors that traditionally did not work together.

Furthermore, there is an issue with the risk perception – for example, asked what the main pest problem is, the question gets automatically translated as "insect problem". It is just assumed that rodents are there but that nothing can be done about it. It is often said that 10 crops need to be planted: 7 for families, 1 for birds and 2 for rats – we should not be at that level of acceptance.

NGOs are an important partner in rodent control programs and should be leveraged whenever possible – they are usually the first ones to receive requests for help with "pest problems" from farmers.

Peru experienced the success of a multi-sector approach when they collaborated with the Ministry of Health to set up a community-based surveillance for dealing with a plague outbreak. They also selected community leaders who could identify diseases, rodents etc. to help with case notification, and provided proper

guidelines on rodent burial techniques to stop further spread of the infection. While the agriculture sector was not involved, they worked with PAHO to develop grain storage facilities in order to demonstrate to the farmers, the amount of crop yield preserved if the harvest is kept away from the rodents.

Many rodent control strategies depend on the availability of funds. The strategy in Brazil has been to associate rodent programs with dengue programs, as a lot of determinants are the same.

The Trade sector is another area that can be leveraged for rodent control collaboration due to the possible economic losses arising from a rodent infestation. For example, a ship from Australia carrying wheat for export was denied entry in China when they discovered a rodent infestation onboard, causing huge losses for the company.

Similarly, the International Health Regulations (IHR) and the Ministry of Transportation that makes the link between invasive species and health, are two important sectors that should also be involved in multisectoral approaches to rodent control programs.

The idea of a learning alliance has emerged in South East Asia: the private sector, farmers, governments, and researchers meet and discuss the rodent control problem together, share experiences and perspectives and start network mapping. While it is difficult for people to listen to the problems of other sectors on the same topic, in presence of the right facilitator, such an alliance can be extremely productive.

Advocacy

Like most public health programs, building local capacity and increasing the knowledge base should be a core component of any rodent control program. Similarly, influencing policy and engaging politicians in the control program should be one of the primary objectives in order to ensure program sustainability. Awareness of policy makers is extremely important.

Rodent control should be built on integrated pest management models, for which local structures are important too.

Researchers should partner up with other sectors such as trade for advocacy work – the initiative itself could be based on one common strategy and one vision, but the language and communication should be adapted to each stakeholder (health, agriculture, trade etc.). Local key champions should be identified.

Local champions should be identified and supported. For example, in Myanmar, local partners have used the power of the International Research Institute to gain support from the Ministry of Health, as well as to bring the Ministry of Health and the Ministry of Agriculture to the same table.

Locally, communities should be empowered and informed on how to request health interventions from the authorities themselves.

Field experiences and research results should be shared with stakeholders and ministries for sustained support. For example, in the port of Cotonou, a new project for surveillance and early warning against invasive species, such as rodents, is underway in collaboration with the Ministry of Health. The project also targets research and capacity building and control and monitoring actions based on the rodents' behavior.

Investigators and researchers must ally with decision makers and the private sector to garner more support – financially and operationally.

From a strategy point of view, it is important to propose practical action plans for financial donors. It is not sustainable for rodent control to remain a research topic only.

Conclusions

In conclusion, there has been some tremendous successes in agriculture with regards to applied techniques for rodent control. Researchers need to collaborate and find ways to repurpose similar techniques and use them for addressing the rodent control issues in public health. All sectors including health and agriculture who are involved in rodent control programs also should strive to integrate a strong monitoring and evaluation component, which analyzes the cost benefit of such programs. Furthermore, if the economic benefits that follows rodent control programs such as reduction in crop damage and lowering health care costs can be quantified, it can serve as a powerful advocacy tool to gain more financial and political support from relevant decision makers.

All sectors (agriculture, natural resources, transport, trade and industry) should be involved, and local partners will be key to leveraging the initiative at the national level. International organizations should leverage their position in certain contexts to initiate discussions between local partners and stakeholders. Finally, the question of scientific results and their application in the real world is an important one – stakeholders should make sure that they ask the right questions to researchers before a control program is initiated.

Day Two – 21 March 2019

Session 4: Gaps and Needs in Research and Development and Capacity Building in Rodent Control

4.1) Presentation: Applied Research and Innovation in Rodent Control

Dr. Jens Jacob (with input from **Dr. S. Belmain**, **Dr. H. Leirs**, and **Dr. G. Singleton**) – Julius Kühn-Institut. Federal Research Centre for Cultivated Plants. Germany.

Dr. Jacob presented on the current state of the various applied research and innovation methods for rodent control from traditional methods such as sanitation and prevention (rodent-proofing) to using biocontrol, trap-barrier systems and fertility control. He articulated the lack of comprehensive evaluation studies for most rodent control programs where each stage from the proof of concept to upscaling and implementation was tested. Dr. Jacob underscored the gaps in knowledge regarding the unwanted effects of various management methods and explained the importance of long-term monitoring and collecting key time series data (climate, human cases etc.) – all of which can be used to predict abundance, damage, and risk to humans. Finally, Dr. Jacob reiterated the common theme of this topic – a cross sectional problem needs a cross sectional solution.

Key Points

While the importance of rodent management in the agriculture sector has been amply demonstrated, the main challenge now is identifying the exact rodent species that need to be controlled as 90% of them are not pest species.

Some applied rodent management methods have been developed and field tested, but there is still a gap in implementing the findings in national guidelines/regulations and translating the knowledge to end users. Furthermore, for meaningful field trails, the methods need to be replicable, appropriately scaled, and consider all relevant parameters, including assessment of non-target effects.

The general objective of rodent control is to reduce damage and infection risk and increase crop yield and net income. For that, the management aim of rodent control needs to be clearly defined, starting with the level to which the rodent abundance must be reduced.

The level of rodent abundance tolerance differs by country and context. For example, in Germany, while 100 rodents per hectare might be tolerated by farmers, 1,000 rodents per hectare are not. In the context of food storage, the tolerance is zero, and when protecting islands, even one pregnant female rodent is one too many.

In agriculture, the goal is to reduce rodent abundance and thereby increase the crop yield. When bioinformatics models were run to compare crop yield when rodent control interventions were implemented vs. when they were not, researchers found that the rodent abundance, crop yield and subsequent net income differs between the two scenarios. They also discovered that the best effect for net income is achieved at a certain time of the year. This means that, once again, crop protection scenarios have to think about economics.

Traditional rodent management methods with new aspects include Sanitation and Prevention:

1. *Sanitation in fields, margins, gardens and settlements*
2. *Rodent-proofing structures*

Some rodent proofing techniques that have been developed include:

- Use of super bags with low gas permeability so that rodents cannot smell its content. In theory there is less damage when those bags are used, and researchers found less holes in the bags.
- Tree bands to keep rats away from coconut farms.
- Fencing seed beds around small high value crops. Recently new fences have been developed that are U shaped and have doors. This way, rodents can enter designated seed beds, but cannot exit, creating the perfect opportunity for predators to eat them.
- Other kind of barriers in habitat management, including root baskets, diversionary feeding, scaring, and repellents.

Lethal rodent management methods include the use of chemicals or biocontrol such as:

Fumigation, especially in rice banks; flooding or hunting.

Rodenticides with acute or delayed action (each mode of action has pros and cons).

Combination insecticides to delayed action rodenticide: This kills arthropod vectors before the rodent dies, minimizing the risk of the vector leaving the dead rodent and moving on to humans. This method has been shown to work against cat fleas as they are exterminated immediately, and flea the population does not recuperate. The rodents started dying four to five days after the fleas were exterminated.

Vaccination: Oral vaccination of wild white footed mice lead to reduction of Nymphal Infection Prevalence (NIP).

Bio-control – Introduction of predators (birds of prey; terrestrial predators; parasites; bacteria) to slow down the rodent population growth or reduce its size. The best example of this method is the use of raptors – a bird of prey – to control rodent population. Another bio-control approach is using the landscape of fear to inform rodent control measures: Animals trade off safety for food – it is ok to be hungry but not to expose yourself for food.

Use of taxon-specific parasites such as *Sarcocystis singaporenisis*: Pythons are the definite host of this parasite and Rattus, etc. are the intermediate hosts. The parasite is integrated within baits that are then

released. This method shows reduced abundance and damage and increased yield. It is recommended in combination with other methods for rodent control.

However, currently there are still many gaps in knowledge about the impact of bio-control including effects on rodent abundance, damage, crop yield and cost-benefit ratios. For example, more than 2,000 papers have been published on bio-control but only 28 evaluated efficacies of some sort, 3 reported on rodent abundance and only one paper was published with decent research methods. Most of the current studies lack proper experimental design and evidence to make any relevant conclusions.

The use of traps at the village scale has been shown to reduce damage to the stored rice. A new method using water canisters to create cheap traps is also being developed. Traps fits along the edge of the field, and predators can come and get the rodent inside. (Belmain et.al 2015 WildRes).

The trap barrier system (TBS) / Community trapping system (cTBS) is the best one known and researched methods for rodent control. It is one of the few examples of a rodent control method where all stages from proof of concept to adoption/up-scaling/implementation into national guidelines have been studied. TBS is an integral part of ecologically-based rodent management (EBRM) in rice crops (Singleton et al. 1999).

Method: A fence is incorporated within the rice field and a crop of higher nutritional value is planted early within it. Rodents enter the fence, are unable to exit, and end up in a multi-fencing system that is accessible to predators.

Results: This approach along with sanitation and an integrated approach produces quite an effect –

- It led to less damage, more yield, and was cost beneficial during village level trials in Vietnam & Indonesia (Brown et al. 2006 EcolApp; Jacob et al. 2010 WildRes).
- It also allows for less use of poison (Singleton et al. 2003 IRRI Notes).
- These systems have a halo effect as they belong to many people and allows the protection of many farmers' crops (200 m halo effect. Brown et al. 2003 IntJPestMan).
- There is a socio-cultural dimension of the ways to get farmers' communities to adopt the strategies (Palis et al. 2007 JIntegrZool) (Palis et al. 2015 JEnvSciMan).

Trap Barrier System – Case Study: In South Sumatra, the trap barrier system allowed farmers to go from 30ha of rice crops in 2012 due to rodents, to 300 ha in 2014 after implementation of a Community trapping system (cTBS) in 2013. They were able to demonstrate rodent management via cTBS and gained funds from the provisional government to support the farmers. In 2015, rice production increased to 17,000 ha and by 2017, the farmers were producing over 100,000 ha of rice along with a third crop that they didn't previously grow.

Non-lethal rodent management method includes fertility control and gene drive technology CRISPR CAS9

Fertility control – reducing in reproductive output instead of increasing mortality. It is a more novel and non-lethal approach which reduces the reproductive potential of the rodents, so that only infertile rodents remain in the system, and no vacant place is created for more rodents.

Over the last decades, different approaches for fertility control in rodents using different compounds have been tried – hormones in the 1960s, virally-vectored immunocontraception in the 1980s and GNRH inhibitors and plant compounds in the 1990s.

Fertility control has been found to be quite useful to dampen the outbreak during rodent population outbreaks (Davis et al. 2002). Researchers found that in house mice, only 30% of females need to be sterilized to reduce a third of the population growth. This leads to a lower population size at the end of reproductive season, which leads to less damage to crops. It should be noted that thresholds exist where effects are not found anymore.

Manipulation of hormonal systems for fertility control can also affect rodent social behavior and cause increases in their movement (Jacob et al. 2008 JWildMan). Furthermore, if hormonal cycles are disrupted, the lack of hormonal competency can get recognized by intraspecific competitors, causing the sterilized population to lose some territory. Therefore, in some instances, fertility control can create a vacant space if such parameters are not taken into account prior to implementing the rodent control programs.

Most recent studies on the effects of hormonal fertility control are from China and laboratory-based with hormones from the 1960's. There is very little known about its risks or field results:

Physiological effects

- Liu et al. 2013 reproductive organs and social behavior.
- Liu et al. 2012 sub fertile effects.
- Liu 2012 behavioral mechanisms in males.
- Liu and Shi 2012 hormone levels and receptor expression.

Population effects

- Liu et al. 2012 plateau pikas – mixed results.

Risk

- Zhang et al. 2014 Degradation in soil and water.

However, fertility control method trials are now underway in Africa (*Mastomys*), America (commensal rodents), Asia (several species), Australia (house mouse), Europe (common vole).

There has also been a rodent control product registration in USA for Norway rats and house mice (Contrapest™).

Gene drive technology: The idea is to create rodent females that can only produce male off-springs using new gene drive technology such as CRISPR CAS. Scientific reviews report that this technique is at too early a stage and that this management technique will not be usable in the foreseeable future. For this method, understanding competitive reproductive performance of rodents is required – a current gap in our collective knowledge.

Prediction of rodent abundance/damage/infection risk

Predictions can be made to time rodent management spatially and temporally, and to predict abundance, damage, and the cost benefit of each intervention. There is often a positive correlation between abundance and damage, and abundance and infection risk (Luque-Larena et al. 2015). In many cases there is also a positive correlation between abundance and weather (Pech et al. 2003) (Leirs et al. 1997 Nature).

Long term monitoring data is needed for prediction analysis (Meese et al. 2018). Creating a time-series based on the monitoring data is the most common method, but more recently, drones are along being used

as well. Drones allow aerial pictures for monitoring rodent abundance and for surveilling the presence of plague hosts (Wilschut et al. 2018 IntJAppEarthObsGeoinf).

For example, weather-based prediction of abundance/human infection risk have been carried out previously by creating an abundance time-series based on monitoring data from 1973-1998 in Germany; and weather time-series based on monthly means data from weather stations for air temp (mean/max/min), precipitation, snow days, and sunshine duration. (Blank et al. 2011, Imholt et al. 2011, Esther et al. 2013).

Weather-based predictions have also been used for the surveillance of the bank vole outbreaks in Germany which are related to hanta virus infection risk to humans. For predictions, regression trees are often used, and the risk is categorized as low, medium, or high, depending on parameters and threshold values. Based on these analyses, outbreak and risk maps can be created for farmers to use and help make rodent control decisions ahead of time.

Since there is a considerable time lag of weather parameters, prediction models can use data from 6 months or 1 – 2 years prior to the population outbreak. For example, in the context of Puumala virus (PUUV) – the most prevalent hantavirus in Germany – and bank voles, their main reservoir, during beech mast years, bank vole populations grow rapidly reaching peak population densities the following year. Therefore, two years of climate data is used as there is a time lag after the beech mast. This system can thus be used to predict problems for human health in advance. In addition, predictions can be made at all geographical levels.

Conclusions

In conclusion, many rodent management methods are available but the efficacy for abundance, damage, yield, income, infection risk is not always clear. The larger the scale of the problem, the less suitable methods seem available. Among currently available rodent management methods, it is an exception that stages of management methods from proof of concept to upscaling and implementation have been studied for their efficacy. Even less is known about the unwanted effects of various management methods with the exception of rodenticides – it is the only method of control for which more is known about population effects, residuals, and unwanted effects. The balance between reducing pest populations and unwanted related ecosystem effects are often not considered in rodent control methods. Long term monitoring is important for gathering time series data to identify patterns and make predictions. This is also an opportunity to many studies combining damage and diseases – cross sectional problems need cross sectional solutions.

References mentioned: Tersago et al., Jacob et al., Hinds et al., Labuschagne et al. 2016, Kay et al. 1994, Brown et al. 2003.

4.2) Expert Panel

Dr. Jens Jacob, Dr. Herwig Leirs, Dr. Grant Singleton, Dr. Hector Coto, and Dr. Federico Costa

Overarching questions

1. How do we scale up proven applied technology and strategies for rodent control? Do we see opportunities for innovative strategies?
2. How do we increase involvement of commercial enterprise in rodent control innovations that target poor end-users?
3. How do we facilitate increased stakeholder awareness about alternative rodent control technologies and strategies?

4. Once there is a rodent population outbreak can we simply document why it happened or can beneficial action be taken?

5. How do we build capacity in both research and applied use in ecologically based rodent management for disease control?

Key Points

Introduction

The WHO is specialized in health and has a mandate through the IHR to control vectors including rodents at entry points. Therefore, the main messages of this initiative need to be global in their range, with a focus on health and its declinations (sociological, economic, etc.). While interventions including rodent control have an associated cost, the initiative should highlight the sustainability of such programs and the importance of implementing some as a preventative measure and not just during outbreaks.

Prior to implementing any rodent control program, it is important to evaluate and take into consideration, the socioeconomic, environmental, and ecological impact of these methods. Currently there is a gap in knowledge regarding the efficacy of most rodent control methods and their impact on human health.

Furthermore, since rodents are at the interface between increased productivity and health, rodent control programs should implicate all sectors including commercial private organizations, irrigation systems, and urban centers (e.g. expansion of the Panama Canal). With intensification of agriculture and deforestation, the environmental problems and thus rodent population densities will continue increasing. Therefore, the programs can longer be one-time interventions without synergy and without considering long term plans – there needs to be proper involvement of all sectors.

During implementation, it is important to incorporate local partners into the program fully to avoid resistance and poor up-take. Furthermore, education to create awareness among the general population including local leaders, students, farmers etc is a key component of successful program implementation.

Finally, improvement of diagnostics for rodent-borne diseases' is just as important as rodent control programs for mitigating the impact of rodents on human health.

How do we scale up proven applied technology and strategies for rodent control? Do we see opportunities for innovative strategies?

While the existing toolbox for rodent control methodologies is impressive and varied, majority have not been tested for their efficacy and very little is known is about their scalability. For example, some rodent control projects have shown the usefulness of satellite imaging to monitor rodent activity, but researchers have been struggling to operationalize the concept and scale it up. In this instance, local people in charge of plague surveillance did not want to take ownership of the method for the fear that it might take away their jobs.

Since trap-barrier systems and community trap-barrier systems are one of the few control methods to have been studied well enough to know that they work, their scalability is crucial. For example, in South-East Asia, community action is essential because each villager's land is about 1 hectare and located right next to the neighbor's land – therefore if only one farmer acts on rodent control, the neighbors' rodents will re-invade. The system is called a Community Trap Barrier (cTBS) system because it benefits a minimum of 100 families (100 hectares).

cTBS is very effective in this context, but its effectiveness has not been proven at larger scales such as Australia, where the average farm size is about 2,000 – 3,000 hectares, and where they are currently experiencing house mice infestation of their crops. The researchers there used zinc phosphide which is specific to the house mice and does not work well for rats every 7 years.

Another approach is to reduce the rodent management area to a smaller size and take immediate action rather than wait for the issue to become a larger outbreak, which with the currently available methods, will require more harmful and less researched interventions – e.g. mass poisoning.

In short, scaling-up of rodent control program needs to happen by educating the general population as well as decision maker, taking climate variability into account, and involving the private commercial industry to put control methods in place on a larger scale.

How do we increase involvement of commercial enterprise in rodent control innovations that target poor end-users?

In medicine, translational research applies knowledge acquired from biomedical research to techniques and tools in clinical practice designed to improve health outcomes. For rodents, we do not have an equivalent practice where knowledge from research settings have been tested in the field and their long-term efficacies and other impacts measured.

Commercial private sectors such as food production companies could be useful translating the basic findings from research into something operational – they have more of an immediate and economic stake in making sure the techniques work.

Furthermore, due to the nature of the size of their operations, the commercial private sector might be the key in testing the scalability of some control methods. The task will be figuring out ways to incorporate the private sectors right from the beginning stages of development of rodent control innovations.

How do we build capacity in both research and applied use in ecologically based rodent management for disease control?

Academia should be strengthened to continue educating and producing rodent control experts. For example, in Argentina, a new national program has been set up for training on vector control experts targeting health workers – the curriculum can be shared with other countries.

Effective rodent control starts with the acknowledgement that its' application is practical and multisectoral, meant to function both for the control of rodents and related human diseases. In many countries, one of the challenges is the lack of rodent specialists or epidemiologists with the knowledge and experience to facilitate such an integration. Furthermore, other essential professionals in the field such as entomologists and rodent experts are diminishing, creating yet another gap in capacity. Finally, to translate to collective knowledge on rodent control into policies, the leaders and decision makers need to be educated first.

An alternative approach could be to carry out syndromic surveillance and develop diagnostic tests to allow validation of methods used for control of rodents. Three axes could be:

- Control and diagnostics to ultimately save lives.
- Creation of hotspots for surveillance that would include socioeconomic and ecological determinants.
- Strategic plan with new capacity building efforts and a one health approach consisting of multidisciplinary team.

How do we facilitate increased stakeholder awareness about alternative rodent control technologies and strategies?

Involvement of organizations in a methodological way.

Involve them from the beginning of the investment project.

WHO as an organization need to provide guidelines for rodent control strategies because currently, the guidelines are issued by private industries who look out for their own interests, and not necessarily the negative environmental and ecological impacts those control strategies might have.

Countries need directives and guidelines of rodent control methods that work so that they demonstrate to the population, the impact of rodent control in reducing damage and the risks to human health.

Monitoring Data and Prediction Models

Another role of WHO, the IHR mandate in particular, calls for the organization to aid member states monitor and respond to outbreaks related to epidemic and epidemic prone diseases – many of which are rodent bone – and to gain a better understanding of their associated risk factors including the environmental, ecological and climatic drivers. Therefore, there is a dire need for data and information related to disease burden, ecology, climate, etc. – at a scale that will allow for an informed perspective on countries and their rodent disease burden, the borders they share, and the nature of human-animal interface specific to their experience.

Predictions based on monitoring data gathered from such initiatives can be used at the country level to raise awareness among the general population, as well as among specific risk groups who might have more exposure to the vector (e.g. tree loggers and farmers). For health care workers, it can be used to forewarn clinicians and epidemiologists about specific disease risks. Not only will the information aid clinicians identify related disease symptoms, it will also help inform the epidemiologists to include the disease in their early warning and response surveillance systems (if it isn't already included), for early detection and timely response to outbreaks. However, if the incidence infections do not change over the years – if it is chronic – then the predictions are useless in that context.

Finland is a great example of a country successfully using long-term monitoring data to predict outbreaks and raise disease awareness among the population. Since the presence of rodents in Finland is extremely cyclic in the forest, long-term monitoring happens twice a year, financed by the department of Forestry. With the data they gathered, they now know to delay tree-planting by a couple of years, so the rodent population crashes first and seedlings survive. They also leverage the media in raising awareness and helping monitor outbreaks. Therefore, while long term monitoring cannot be used to exterminate rodents, it can be used to warn people about possible outbreaks and risks.

However, some of the current challenges in gathering the needed information are : (i) difficulty gathering data on rodents who have outbreaks once every two to five years, including the lack of capacity to monitor rodents for a long time, (ii) continuous research rarely conducted on pathogens present in rodents, (iii) at the human level – rodent borne diseases are not notifiable, therefore their true burden is not known.

One way to gather data on pathogens found in rodents could be a collaboration between operational researchers using the Trap Barrier Method (TBM) for rodent control and biomedical researchers/epidemiologist who could collect the rodents from the traps and test them for various pathogens. This could help quantify circulating pathogens. The researchers could also design questionnaires to collect clinical data close to capture sites (all georeferenced).

Insecticides/Rodenticides

Regarding the use of rodenticides, each country has their own regulations. BioRat was banned by many countries and advised by CDC and WHO to be removed from the market.

In Europe due increasing environmental awareness, they have very strict regulations for insecticide. The private sector does have their own guidelines for control etc. but are only permitted to use registered products. The registration process is long and rigorous – it tests the efficacy and environmental impact of the compound– and if the it fails the tests; it does not get registered. Thus, only one authorized compound is now left in Germany, similar to the rest of Europe.

In Peru, fleas have shown resistance to insecticides and advice was asked on what other countries use. Fipronil was highly recommended but it is important to test the fleas for resistance first. The colleagues from Peru responded that they did try Fipronil previously but observed high toxicity in both humans and animals. This highlighted the need for pesticide and acaricides' regulations, systematization of their implementation, and incorporation of a monitoring and evaluation component to the intervention. Furthermore, it was mentioned that new studies show that Fipronil might be related to microcephaly associated with zika virus infection.

Considerations for the Road Map

A comprehensive literature review of currently available rodent control methods and any evidence generated from related studies is needed.

A gold standard for long-term efficacy testing: There is a need to clarify the criteria for assessing whether a rodent control program worked or did not work – a gold standard for long term efficacy testing. Currently most control programs are never monitored or if they are, they are evaluated in abstract ways (e.g. how much poison was consumed) without ever demonstrating/quantifying the clear benefits to peoples' lives. Since no proof of benefit related to the control program is generated, funding for the program including efficacy testing either decreases or is eliminated altogether, resulting in a cycle of control programs whose efficacy is unknown but yet is the only available control program. Therefore, what indicators should be measured for monitoring and evaluation? Rodent populations? Diseases? Damages to crops and property?

- One approach could be to be to conduct smaller case studies to determine a gold standard technique which works for health-related outcomes – with the results, advocacy work for the bigger picture of the initiative can begin.
- Collaborating with public health program implementation Monitoring and Evaluation (M&E) experts should also be considered while designing a study/control program.

Do countries have functioning programs for rodent control? If not, what are some ways to encourage/advocate for countries to incorporate rodent programs into their public policies?

Conclusions

After a review of the existing rodent control methods, this panel discussion touched on their cost-effectiveness and sustainability, the need for training of experts and predictive models for decision making, the importance of a one health approach which is integrated and multisectoral, the possible collaborations with private sectors, socio-economic factors associated with rodent control, and finally, the responsibility of international organizations and the current initiative to support the implementation and application of rodent control programs at all levels (national and sub-regional).

Session 5: Roadmap Discussion

Participants were divided into four working groups composed of a variety of experts, to discuss the conclusions of sessions 1 – 4, and distill relevant strategies, concepts and questions to be included in the roadmap. Each group presented their findings to the larger audience at the end of the exercise and further discussions were held. The discussions for each group were guided by the following topics:

1. The issue of rodents and their control: What we all agree on.
2. Multifaceted impact of rodents on human health and the importance of multisectoral collaboration and engagement.
3. Gaps and needs in research and development in rodent control.
4. Gaps and needs in capacity building in rodent control.

Key Points

The issue of rodents and their control: What we all agree on

The issue of rodent control is multifactorial and multisectoral, therefore requires an equally multisectoral approach that reaches all levels (local, regional, national, and global), and takes into account, the interactions between health, climate, food systems, environment, and society (including socio-economic factors, cultural and religious aspects, population structure and growth, and conflict). One health is a possible approach.

Rodent control should be built on integrated pest management models, for which local structures are important considerations. The objective is not total rodent population eradication, but more about finding ways to balance the ecological and socioeconomic determinants which impacts rodent population (with some exceptions: ports and outbreaks).

Since rodent control often requires the combination of different methods, education is key to increasing awareness in the general population and expanding the knowledge base of relevant stakeholders. Furthermore, there is a need to train more entomologist and rodent experts in the younger generation as the number of current and former experts are dwindling.

While the aim is to achieve Rodent control at a global scale, the best approaches seem to be when a technique is adapted to the local context. There is no one size fits all rodent management programs.

Advocacy for rodent control program requires political engagement beyond the field of health – influencing policy and engaging politicians should be a core component of any rodent control program. Organizations like WHO should advocate for and encourage countries to incorporate rodent programs into their public policies.

<u>The following gaps and needs should be prioritized</u>:

- Monitoring and Evaluation – Currently there is a gap in knowledge regarding the efficacy of most rodent control methods and their impact on human health.
- Rodent borne disease data related to human health collected in relation to time and space.
- Monitoring, surveillance and integration of rodent borne diseases into early warning systems.
- Long term monitoring data including weather and ecological data for prediction analysis.

- A long-term perspective for control strategies in the context of urban areas versus semi-urban, peri-urban and agricultural settings.
- Improved and standardized diagnostic, surveillance, and monitoring and evaluation tools for rodent borne diseases.
- A way to structure and frame the research questions related to the Sustainable Development Goals (SDG) to gain future funding opportunities.

Immediately Actionable Steps

- A comprehensive literature review of currently available rodent control methods and any evidence generated from related studies.
- Review of all the currently available training materials and decide as a group, which one to recommend for the interim while developing a new, updated one.
- Consultation with monitoring and evaluation experts on improving rodent control program implementation by helping select the right indicators to measure in health, agriculture, infrastructure, etc.
- An open access online matrix listing the already existing tools, settings and capacities for rodent control.

Objectives

- A gold standard for long term efficacy testing of rodent control programs.
- Concrete rodent control guidelines that can be adapted to context – even with modest amount of evidence that currently exists.
- Cost-benefit analyses of the social and economic impact of rodent borne epidemics that can be used for advocacy and communication to stakeholders.
- Risk assessment of health impact from known and unknown rodent borne pathogens during outbreak settings vs. an endemic setting.

Multifaceted impact of rodents on human health and the importance of multisectoral collaboration and engagement

In the context of methodologies for rodent control, it is important to:

- Take a multisectoral approach (health, food, agriculture, climate, animal health, trade, the private sector, and even the army). Maybe link control techniques to the one health strategy which is multisectoral by design.
- Involve multisectoral actors as early as needed, depending on context for pilot studies and case study.
- Collaborate with decision makers at all levels of government from farmers to mayors, because each can play an important role in success of the program.
- Research and understand the impact of rodents at different levels (health, water and sanitation, food production including economic impart).
- Monitor the impact of rodenticides and pesticides on the environment and human health as well as potential side effects on other species.

- Create a Proof of Concept to make sure that a program is effective in terms of security and control of diseases. This way multisectoral teams can be efficiently created.
- Combat barriers in communication by educating funding agencies and sharing results of field studies to secure future grants.
- Leverage the media and other communication channels at all levels, from local to the national level to create awareness and carry out risk communication.

Gaps and needs in research and development in rodent control

- Indicators to measure rodent impact on health, agriculture (food), and damage (infrastructure) – all of which will help asses rodent control strategies.
- Assessment of multiple outcomes of rodent control through case studies (food resources, pathogens).
- Cost-effectiveness studies of rodent control measures.
- More research on urban and suburban rodent ecology.
- More research on pathogenic and zoonotic agents in rodent borne diseases.
- Clarity on the impact of biodiversity on rodent borne diseases.
- More research on the ecology of rodents, their social and environmental determinants, and the impact of rodent control on health and transmission of diseases.
- List of sites that are currently doing long term monitoring series.
- Review of national capacities of rodent control and surveillance in all the different countries.
- Animal models to study rodent behavior and to set setting and models on how to study them and how to modify some components to understand better their behavior in the field.
- Collaboration with social science experts to better understand the behavior of rodents and the behavior people with the rodents.
- A common database that can shared with other experts on the burden of rodent borne diseases, risk factors, etc. – a type of global surveillance/collaboration site for rodent borne diseases.
- Case control studies based on previously successful control methods to test scalability and interoperability in other contexts (health, agriculture, Sea Ports etc.).

Gaps and needs in capacity building in rodent control

Essential professionals in the field such as entomologists and rodent experts are diminishing, creating yet another gap in capacity for rodent control. The research community needs to advocate for training more of these professionals for the next generation, especially since the complexity related to rodents and its impact on human health are just now being explored. The next generation of researchers need to be trained to better understand the role of rodents in public health, and the institutions training them should be encouraged to include field trainings in addition to classroom lectures in their curriculum.

Some of the other needs in capacity building with regards to rodent control include:

- Combined capacity building training for policy makers and researchers.

- Trainings for rodent control integrated with different areas (private industry etc).
- Global training on ticks, mites, parasites etc.
- Standardized training on field ecology and upscaling by regions of the world.
- Identifying structures that be used for rodent control and/or creating them (IHR).
- Standardized training documents to further train staff on the field.
- Facilitate access to information on up-to-date technologies for rodent pathogen surveillance (WHO job).
- Capacity for translating research findings related to rodent control into operational use on the field.
- Methods for risk mapping, stratification, GIS, and big data, and for prediction models.
- Broad programs with multisectoral participants (center of excellence, create or elaborate).
- Capacity building for research, data collection, and outbreak control on rodent borne diseases. Maybe collaborate with field epidemiology programs: how to identify symptoms of diseases, etc.

The advantage of having a team of rodent experts, is that the initiative can create a set of reference documents that we all agree on. The group could review all the currently available training materials and decide if any can be recommended for use in the interim while the group collaborates on a new one. In terms of strategy, visibility and fundraising, training materials are a great advocacy tool since they are viewed as useful right away, which can then be used as a starting point for initial collaboration with donors and stakeholders.

Notes: Handbook on rodent identification ACIAR.gav.au publications book by Aplin K. which lists information on basic biology, ecology and other social aspects of rodent management.

Conclusion

The Expert Meeting on "Innovative control approaches of rodent-borne epidemic diseases and other public health consequences of rodents' proliferation" held in Lima, Peru between 20 March and 21 March 2019, aimed at initiating a kickoff meeting for a new and novel, international and inter-sectoral initiative that would advocate and develop innovative prevention and control strategies to mitigate rodents' impacts on human health. The participants not only had an opportunity to share their own experiences during presentations and panel discussions, but they were also invited to share posters of any relevant research they are involved in during the coffee breaks, which added fresh perspectives to group discussions. At the end of two days, participants identified some key areas that they all agreed on with regards to rodent control: (i) The issue of rodent control is multifactorial and multisectoral, therefore requires an equally multisectoral response in the spirit of One Health (ii) Rodent control should be built on integrated pest management models, for which local structures are important considerations (iii) While the existing toolbox for rodent control methodologies is impressive and varied, the majority have not been tested for their efficacy and/or cost-benefit profile; and very little is known is about their scalability, and (iv) The goal is not to eradicate rodent populations but rather to achieve an environmental and socioeconomic balance between humans and rodents.

The meeting was also an opportunity to identify key experts and stakeholders who could and are willing to support the initiative. At the end of two days, participants collaborated on the design of a roadmap by identifying priorities for research and development, capacity building and investment case with regards to rodent control: (i) Development of efficiency and effectiveness benchmarks – a type of gold standard – to evaluate existing and future control methods, (ii) More research on the ecology of rodents – their social and environmental determinants, (iii) Assessment of multiple outcomes of rodent control through case studies, (iv) Operational research to translate bench-research into field interventions, (v) Training of essential professionals such as entomologists and rodent experts who are diminishing, (vi) Guidebooks/tutorials on rodent control, (vii) Capacity building for research, data collection, and outbreak control on rodent borne diseases, and (vii) Better surveillance systems and diagnostic tools for rodent borne diseases.

In addition to the above-mentioned needs and gaps, a common theme identified throughout the workshop was the need to implement or improve on some key components of an effective public health program implementation strategy in the current and future rodent control programs. The key components include: (i) Managing performance via monitoring and evaluation; (ii) Multisectoral Partnerships including the private sector; (iii) Communication for advocacy, education and behavioral & perception change; and (iv) Political Commitment needed to coordinate, implement, and sustain public health interventions, including policy change where needed.

Based on the group discussions, the general objectives of the initiative especially in the context of public health, were described as: (i) guide and coordinate operational research; (ii) develop targeted prevention and control strategies for rodents and their ectoparasites; (iii) facilitate the implementation of these pro-

grammes in countries that request them, in crises or otherwise; (iv) train specialists at the international, regional and national levels; (v) improve prevention and control strategies for rodent-borne diseases with the greatest impact on public health.

Next Steps

One Month After

- Meeting Report.
- Publication in the Weekly Epidemiological Report: https://www.who.int/wer/2019/wer9417/en/.

Short-Term Goals

- Concept paper in a peer-review journal.
- Roadmap (technical annex + roadmap itself).

Medium-Term Goals

- A survey of rodent population monitoring, prevention, and control methods to compile a list of most relevant approaches and those requiring further evaluation.
- A preliminary inventory of skills, structures and training tools to be developed as soon as it is possible to analyze the needs.
- A gold standard for long term efficacy testing of rodent control programs.

Closing Remarks

To close the meeting, the WHO/PAHO Health Emergencies representative, Dr. Sylvain Aldighieri on behalf of the country and regional office, thanked the participants and complimented them on the dynamics of the meeting, filled with good team spirit and team building attitudes. Experts from different backgrounds and different regions were all able to share their data and field experiences with each other. Dr. Aldighieri commented how from the coffee break discussions he overheard, it sounded like the most established group of rodent experts had been gathered by WHO to tackle the rodent issue and how he hoped that the networking was helpful for everyone's own research as well. Dr. Aldighieri also hoped for the participants to have gained a better idea of how PAHO works together with its member states. He thanked the Peru Ministry of Health in their support of the meeting as well as the Peruvian colleagues who attended and shared all their field experiences and knowledge on the topic. Finally, Dr. Aldighieri thanked DLID for their support with the workshop and reminded the participants that all the shared knowledge and discussions during the workshop happened for the sake of a safe and secure global public health.

Dr. Eric Bertherat reminded everyone that for the initiative to be successful, structure and funds are needed. WHO will assume its health role and coordinate all relevant partners – not just the UN agencies, but also other international organizations like WFP, OIE etc. – so that an intersectoral approach is maintained for the initiative. The approach will also remain broad with respect to rodents and human health, and all aspects of the initiative will be in line with the global program of work of WHO to better the lives of the poorest.

Appendix 1

Agenda

Day 1		
Time	***Agenda and objectives***	***Moderator / Presenter***
08.00-08.30	Registration	
08.30-09.00	Welcome remarks	MOH, PWR-PER, Sylvain Aldighieri
09.00-09.15	Background report, meeting objectives and expected outcomes	Eric Bertherat
09.15-09.45	Introduction of participants	Ana Riviere Cinnamond
09.45-10.00	Group photo	
10.00-10.30	**Coffee break**	
10.30-11.30	Key note presentation: Comprehensive overview of rodent problems	Steve Belmain (University of Greenwich)
Session 1: Rodents' borne diseases and epidemics		
11.30-11.50	Presentation: Lassa fever in Nigeria – experience and lessons learned [Posters on: plague, leptospirosis, rickettsia, hantavirus, arenavirus and other rodent-borne diseases]	Ayodeji Olayemi (Obafemi Awolowo University)
11.50-13.00	Expert panel: • Ayodeji Olayemi • Claudia Muñoz-Zanzi • Daniel Paris • Heikki Henttonen • Soanandrasana Rahelinirin Panel questions for debate: 1. What are the commonalities and differences in how rodents should be controlled for different diseases? 2. How do we integrate and express chronic health impacts alongside mortality-focused data for different diseases? 3. What should be done about rodent control during/after disease outbreaks? [Conclusions session 1]	Moderator: Eric Bertherat (WHO) Note taker: Tshewang Dorji Soledad Colombe
13.00-14.00	**Lunch**	
Session 2: Biodiversity, International Health Regulations and urban settings		
14.00-14.30	Presentation: Urban rodent diversity and human health: the case of African cities [Posters on: Rodents and IHR, Rodent control in urban settings, role of biodiversity in rodent pest regulation]	Gauthier Dobigny (Research Institute for Development, Benin)

Day 1		
Time	***Agenda and objectives***	***Moderator / Presenter***
14.30-15.40	Expert panel: • Thomas Bagan • Gauthier Dobigny • Herwig Leirs • Lourens Swanepoel • Jason Tan	Moderator: Steve Belmain (University of Greenwich)
	Panel questions for debate: 1. How is maintaining biodiversity important for rodent pest regulation? 2. Are there ways to mitigate continued anthropogenic and climate changes affecting incidence of rodent borne diseases? Do we understand enough about such effects? 3. What are the main differences and similarities in approach and delivery of rodent control in urban vs. rural environments? [Conclusions session 2]	Note taker: Tshewang Dorji Soledad Colombe
15.40-16.00	**Coffee break**	
Session 3: Multifaceted impact of rodents on human health and the importance of multi-sectoral collaboration and engagement		
16.00-16.30	Presentation: Rodents' impact on agricultural productions and public health: A One health approach	Marisa Caipo (Food and Agriculture Organization, Regional Office for Latin America and the Caribbean)
16.30-17.45	Panel questions for debate: 1) What lessons for rodent disease control can be learned from efforts to control rodents in agriculture? 2) How can we facilitate a multi-sectoral approach to rodent control across different stakeholders, e.g. donors, international agencies, government departments, researchers, NGOs? 3) How do we quantify and express the multiple effects of rodents on people's livelihoods (health, agriculture, environment, economics)? [Conclusions session 3]	Moderator: Herwig Leirs (University of Antwerp) Expert panel: • Marisa Caipo • Oswlado Cabanillas • Grant Singleton • Nyo Me Htwe • Sudarmaji
17.45-18.00	Wrap up day 1	Ana Riviere Cinnamond

Social Event:

Dinner at the Restaurant La Huaca Pucllana @ 8:00PM

Day 2		
Time	***Agenda and objectives***	***Moderator / Presenter***
08.30-08.45	Summary of day 1 and agenda for the day	Soledad Colombe
Session 4: Gaps and needs in research and development and capacity building in rodent control		
08.45-09.15	Presentation: Applied research and innovation in rodent control [Posters on: Urban rodent control for leptospirosis management, fertility control, innovations in non-chemical control]	Jens Jacob (Julius Kühn Institute)

Day 2		
Time	***Agenda and objectives***	***Moderator / Presenter***
09.15-10.30	Panel questions for debate: 1. How do we scale out proven applied technology and strategies for rodent control? Do we see opportunities for innovative strategies? 2. How do we increase involvement of commercial enterprise in rodent control innovations that target poor end-users? 3. How do we facilitate increased stakeholder awareness about alternative rodent control technologies and strategies? 4. Once there is a rodent population outbreak can we simply document why it happened or can beneficial action be taken? 5. How do we build capacity in both research and applied use in ecologically based rodent management for disease control? [Conclusions session 4]	Moderator: Jean-Marc Gabastou (PAHO) Expert panel: • Jens Jacob • Ken Gage • Herwig Leirs • Grant Singleton • Hector Coto • Federico Costa
10.30-11.00	**Coffee break**	
Session 5: Roadmap discussion		
11.00-11.30	Presentation: Report and roadmap proposal/structure Working groups dynamics	Eric Bertherat Soledad Colombe
11.30-12.30	Working groups on integration of conclusions of sessions 1 to 4 into the Road-map "World Café": 4 working groups (to integrate conclusions of each session) 1. Rodents' borne diseases and epidemics. 2. Biodiversity, IHR and urban settings. 3. Multifaceted impact of rodents on human health and the importance of multisectoral collaboration and engagement. 4. Gaps and needs in research and development and capacity building in rodent control.	Moderators: Eric Bertherat Soledad Colombe Ana Rivière Cinnamond Jean-Marc Gabastou
12.30-13.30	**Lunch**	
Session 5: Roadmap discussion (cont')		
13.30-15.30	Working groups on integration of conclusions of sessions 1 to 4 into the Road-mapWorld Café": 4 working groups (to integrate conclusions of each session) 1. Rodents' borne diseases and epidemics. 2. Biodiversity, IHR and urban settings. 3. Multifaceted impact of rodents on human health and the importance of multisectoral collaboration and engagement. 4. Gaps and needs in research and development and capacity building in rodent control.	Moderators: Eric Bertherat Soledad Colombe Ana Rivière Cinnamond
15.30-16.00	**Coffee break**	
16.00-17.00	Finishing the roadmap – next steps	Eric Bertherat Steve Belmain
17.00-17.30	Conclusions	Eric Bertherat
17.30-18.00	Closing remarks	PWR-PER, Sylvain Aldighieri

Appendix 2

Participant List

Name	*Email*	*Institution*
Eric Bertherat	bertherate@who.int	Advisor, Infectious Hazards WHO Health Emergencies Infectious Hazards Management Unit (IHM)
Soledad Colombe	soledad.colombe@gmail.com	EPIET Fellow Folkhälsomyndigheten Stockholm, Sweden ECDC European Programme for Intervention Epidemiology Training
Oswaldo Cabanillas	joswacaba@yaohoo.com.pe oswacaba@hotmail.com	Ex-Director Ejecutivo de la Dirección de Prevención y Control de Enfermedades Metaxénicas y Zoonosis Dirección General de Intervenciones Estratégicas en Salud Pública Ministerio de Salud - PERU
Cesar Cabezas	ccabezas@ins.gob.pe	Instituto Nacional de Salud (INS) Enfermedades infecciosas y tropicales Lima - PERU
Manuel Cespedes	manuel.cespedesz@gmail.com	Instituto Nacional de Salud Director de Oficina Ejecutiva de Gestión de la Calidad Lima- PERU
Laurent Filleul	Laurent.FILLEUL@santepublique france.fr	Coordonnateur de la strategie Outre-mer Santé publique France Bordeaux, FRANCE
Valérie choumet	valerie.choumet@pasteur.fr	Group Leader ENVIRONMENT AND INFECTIOUS RISKS Institut Pasteur PARIS FRANCE
Nadia Khelef	nadia.khelef@pasteur.fr	Senior Advisor on Global Affairs Institut Pasteur PARIS FRANCE
Michel Jancloes	michel.jancloes@gmail.com	Former WHO strategic advisor and director Member of the Health and Climate Foundation GLEAN member and former co-chair
Steve Belmain	s.r.belmain@gre.ac.uk	Professor of Ecology Agriculture, Health and Environment Department Natural Resources Institute, Faculty of Engineering & Science Natural Resource Insitute University of Greenwich
Alain Santandreu	alain_santandreu@yahoo.com	ECOSALUD Peru
Gregory Harlt	hartlgre@paho.org	Communication Advisor South America Sub-Regional Office PAHO

Name	*Email*	*Institution*
Blas Armien	barmien@gorgas.gob.pa	The Gorgas Memorial Institute for Health Studies (GMI) l ICGES Departamento de Investigacion de Enfermendades Emergentes y Zoonoticas - Panamá, Panama Head of Department Panama
Gyanendra Gongal	gongalg@who.int	Advisor Zoonotic Diseases and Food Safety SEARO Office in India WHO
Herwig Leirs	herwig.leirs@uantwerpen.be	Professor Department of Biology, Evolutionary Ecology Group Campus Drie Eiken Universiteitsplein 1, D.D.133, 2610 Wilrijk België
Grant Singleton	g.singleton@irri.org	Cluster Leader - Adaptive Agronomy and Pest Ecology International Rice Research Institute (IRRI) Pili Drive, Los Baños, Laguna 4031, Philippines
Andrea Vicari	vicarian@paho.org	Advisor, Infectious Hazards PAHO Health Emergencies Infectious Hazards Management Unit (IHM)
Patricia Najera	najerapa@paho.org	Advisor, Geographic Analysis PAHO
Federico Costa	fcosta2001@gmail.com	Professor (Associate) Universidade Federal da Bahia Salvador, Brazil
Kenneth Gage	klg0@cdc.gov	Director, Division of Vector-Borne Diseases, National Center for Emerging and Zoonotic Infectious Diseases (NCEZID) CDC - USA
Heikki Henttonen	heikki.henttonen@luke.fi	Heikki Henttonen Professor of Forest Zoology Terrestrial Population Dynamics Natural Resources Institute Finland POB 2 FI - 00790 Helsinki Finland
Lourens Swanepoel	lourens.swanepoel.univen@gmail.com	University of Venda l univen Department of ZoologyThohoyandou, South Africa Senior lecturer
Soanandrasana Rahelinirina	rahelinirina@pasteur.mg	Mammalogiste Unité peste Institut Pasteur - Madagascar
Ayodeji Olayemi	ayyolayemi@yahoo.com	Senior Research Fellow, Mammalogy Museum of Natural History (NHM) Obafemi Awolowo University OAU Ife-Ife NIGERIA
Thomas Bagan	thomasbagan@yahoo.fr	Chef du Département Gestion de l'Environnement/ PAC Ingénieur en Environnement Spécialiste en Aménagement et Gestion des Ressources Naturelles

Name	*Email*	*Institution*
Jason Tan	Jason_TAN@nea.gov.sg	National Environment Agency Singapore
Claudia Muñoz-Zanzi	munozzan@umn.edu	Associate Professor, Division of Environmental Health Sciences Divison of Environmental Health Science University of Minnesota
Renata Olivera	reoliveira@ioc.fiocruz.br	Laboratório de Hantaviroses e Riquetsioses Instituto Oswaldo Cruz Pavilhão Hélio e Peggy Pereira Avenida Brasil, 4365, Manguinhos Rio de Janeiro/RJ - BRAZIL
Pablo Tortosa	pablo.tortosa@univ-reunion.fr	University of La Réunion Department of BiologySaint-Denis, Reunion Associate Profesor
Sudarmaji	sudarmaji2@yahoo.com	Assessment Institue for Agricultural Technology of Yogyakarta Jln. Stadion Maguwoharjo No. 22 Wedomartani, Ngemplak, Sleman 55584 Yogyakarta, Indonesia
Nyo Me Htwe	nyomehtwe@gmail.com	Rodent Ecologist Plant Protection Division Department of Agriculture Myanmar
Daniel Paris	daniel.paris@swisstph.ch	Medical Director, Head of Department Swiss Tropical and Public Health Institute BaseL - SWITZERLAND
Delia Enria	deliaenria@gmail.com	Instituto Nacional de Enfermedades Virales Humanas "Dr. Julio I. Maiztegui" Monteagudo 2510 2700 – Pergamino, Argentina
Ana Rivière Cinnamond	rivierea@paho.org	Advisor, DMAP Health Information Management (HIM) PAHO
Jean-Marc Gabastou	gabastouj@paho.org	Advisor Laboratory Network PAHO PHE - PWR MEX
Tshewang Dorji	Dorjitsh@paho.org	PAHO Health Emergencies Health Management and Information Unit (HIM)
Sylvain Aldighieri	aldighsy@paho.org	Deputy Director, PHE
Hector Coto	hectorcoto@live.com	PAHO Consultant Rodent control expert Argentina
Anabel Sinchi	asinchi@anlis.gov.ar	Departamento de Virología Administración Nacional de Laboratorios e Institutos de Salud ANLIS - ARGENTINA
Judith Mora	jmora@ispch.cl	Jefe Subdepto. Virología INSTITUTO DE SALUD PUBLICA DE CHILE (ISP) CASILLA: 48, AV. MARATHON 1000, NUNOA SANTIAGO-CHILE

Name	*Email*	*Institution*
Jens Jacob	jens.jacob@julius-kuehn.de	Professor Julius Kühn-Institut (JKI) Federal Research Centre for Cultivated Plants Messeweg 11/12 38104 Braunschweig, Germany
Eshan Mostafavi	mostafaviehsan@gmail.com	Institut Pasteur International Network Pasteur Institute of Iran Associate Professor
Dobigny Gauthier	gauthier.dobigny@ird.fr	L'Institut de recherche pour le développement (IRD) Niamey, Niger
Marisa Caipo	marisa.caipo@fao.org	Food Safety Officer Food and Agriculture Organization Regional Office, Santiago de Chile
Maria Laura Martin	malalamar@gmail.com	Dinámica de roedores INEVH Pergamino Argentina