PAAT
Programme
Against
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Trypanosomosis

Vector control and the elimination of gambiense human African trypanosomiasis (HAT)

Joint FAO/WHO virtual expert meeting
5-6 October 2021

PAAT MEETING REPORT SERIES / ISSUE 1

Food and Agriculture Organization of the United Nations
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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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Abbreviations and acronyms

AAT	African animal trypanosomosis
AU	African Union
AW	area-wide
BMGF	Bill & Melinda Gates Foundation
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
CIRDES	Centre international de recherche-développement sur l'élevage en zone subhumide
COCTU	Coordinating Office for Control of Trypanosomiasis in Uganda
CRID	Centre for Research in Infectious Diseases
FAO	Food and Agriculture Organization of the United Nations
gHAT	gambiense human African trypanosomiasis
HAT	human African trypanosomiasis
HAT-e-TAG	HAT-elimination Technical Advisory Group
IAEA	International Atomic Energy Agency
ICCT	Instituto de Combate e Controlo das Tripanossomíases
IPM	integrated pest management
IPR	Institut Pierre Richet
IRD	Institut de recherche pour le développement
IRED	Institut de recherche en élevage pour le développement
ITM	Institute of Tropical Medicine
LAMP	loop mediated isothermal amplification
LPF	livestock protective fences
LSTM	Liverpool School of Tropical Medicine
NaLIRRI	National Livestock Resources Research Institute
NSSCP	National Sleeping Sickness Control Programme
NSSEP	National Sleeping Sickness Elimination Programme
NTDs:	neglected tropical diseases
OIE	World Organisation for Animal Health
PAAT	Programme against African Trypanosomosis
PATTEC	Pan-African Tsetse and Trypanosomiasis Eradication Campaign
PCA	phased conditional approach
PCR	polymerase chain reaction
rHAT	rhodesiense HAT
RNA	ribonucleic acid
SIT	sterile insect technique
SOP	standard operating procedures
TCP	technical cooperation project
UTCC	Uganda Trypanosomiasis Control Council
UWA	Uganda Wildlife Authority
WHA	World Health Assembly
WHO	World Health Organization

Executive summary

The World Health Organization (WHO) is responsible for strengthening and coordinating global efforts aimed at the elimination of human African trypanosomiasis (HAT), a vector-borne disease transmitted by tsetse flies in sub-Saharan Africa. To this end, WHO established the Network for HAT elimination. The network is structured in working groups, and technical and coordination meetings are organized within its framework. The Food and Agriculture Organization of the United Nations (FAO) collaborates with WHO and supports its goals within the framework of the Programme against African Trypanosomosis (PAAT).

The present meeting focused on vector control and the elimination of gambiense HAT (gHAT), the form of the diseases that is endemic in western and central Africa. gHAT is responsible for over 95 percent of HAT cases reported annually, and it is considered mainly anthroponotic (that is, with tsetse flies transmitting the disease from human to human). The number of reported cases of the disease decreased by more than 95 percent in the past 20 years, mainly thanks to reinforced medical interventions (i.e. case detection and treatment). Vector control also contributes to curbing transmission by reducing tsetse-human contact.

In the new WHO road map for neglected tropical diseases 2021–2030, gHAT is targeted for elimination of transmission. The present meeting was the first of the WHO network for HAT elimination that focused specifically on vector control and gHAT, and it included health officials from endemic countries, research and academic institutions, international organizations and the private sector.

The main purpose of the meeting was to review tsetse control tools, activities and their contribution to the elimination of gHAT and the monitoring thereof. Seven endemic countries provided reports on recent and ongoing vector control interventions at the national level (Angola, Cameroon, Côte d'Ivoire, Chad, Democratic Republic of the Congo, Guinea and Uganda). Country reports focused on the institutions implementing and supporting vector control activities, the tools and the approaches in use, the coverage of the activities in space and time and their impacts on tsetse populations. Future perspectives for vector control in the respective countries were also discussed, including opportunities and challenges to sustainability.

Country reports were followed by thematic sessions. The first focused on vector control tools and approaches, including insecticide-treated targets, insecticides treated livestock and livestock protective fences. Area-wide integrated management of tsetse with a sterile insect technique component was also discussed. The main gaps and research needs were addressed, with a view to improving existing tools. A second thematic session dealt with the cost of vector control in the context of gHAT elimination, with a focus on 'tiny targets'; the feasibility of community-based tsetse control was also addressed with a case study from the Democratic Republic of the Congo. Tsetse control in the context of gHAT elimination was discussed in the broader framework of One Health, and in particular in relation to the control of animal trypanosomosis. The third and last thematic session looked at the metrics for the estimation of the impact and coverage of vector control in space and time, with a view towards improved, harmonized reporting and monitoring.

The possible contribution of entomological indicators to the process of verification of gHAT elimination was also discussed.

The meeting concluded that vector control contributes to decreasing gHAT transmission by reducing tsetse-human contact; and therefore, combined with the other existing tools, it is a valuable tool to support the elimination of the disease. In this context, there is a need to adapt vector control activities to the different local epidemiological conditions, selecting the most adequate tools for each setting and prioritizing the areas where the impact of vector control can be highest.

Introduction

BACKGROUND

Human African trypanosomiasis (HAT), also known as sleeping sickness, is a vector-borne disease transmitted by tsetse flies (Büscher *et al.*, 2017). The gambiense form of HAT is found in western and central Africa, and it is mainly anthroponotic (that is, transmitted from human to human via the tsetse vector); the rhodesiense form is found in eastern and southern Africa, and it is considered zoonotic (that is, transmission to humans via tsetse often originates from wild or domestic animals) (Simarro *et al.*, 2010).

Galvanized by 20 years of dramatic progress in disease control, the World Health Organization (WHO) has now targeted the elimination of gambiense HAT transmission by 2030. This goal has been included in the new WHO roadmap for neglected tropical diseases (NTDs) 2021–2030: Ending the neglect to attain the Sustainable Development Goals (WHO, 2020).

Progress in gambiense HAT (gHAT) control over the past 20 years has mainly relied on medical interventions (that is, case detection and treatment) (Franco *et al.*, 2020). Vector control also contributes to curbing transmission by reducing tsetse-human contact (WHO, 2013).

SCOPE AND PURPOSE OF THE EXPERT MEETING

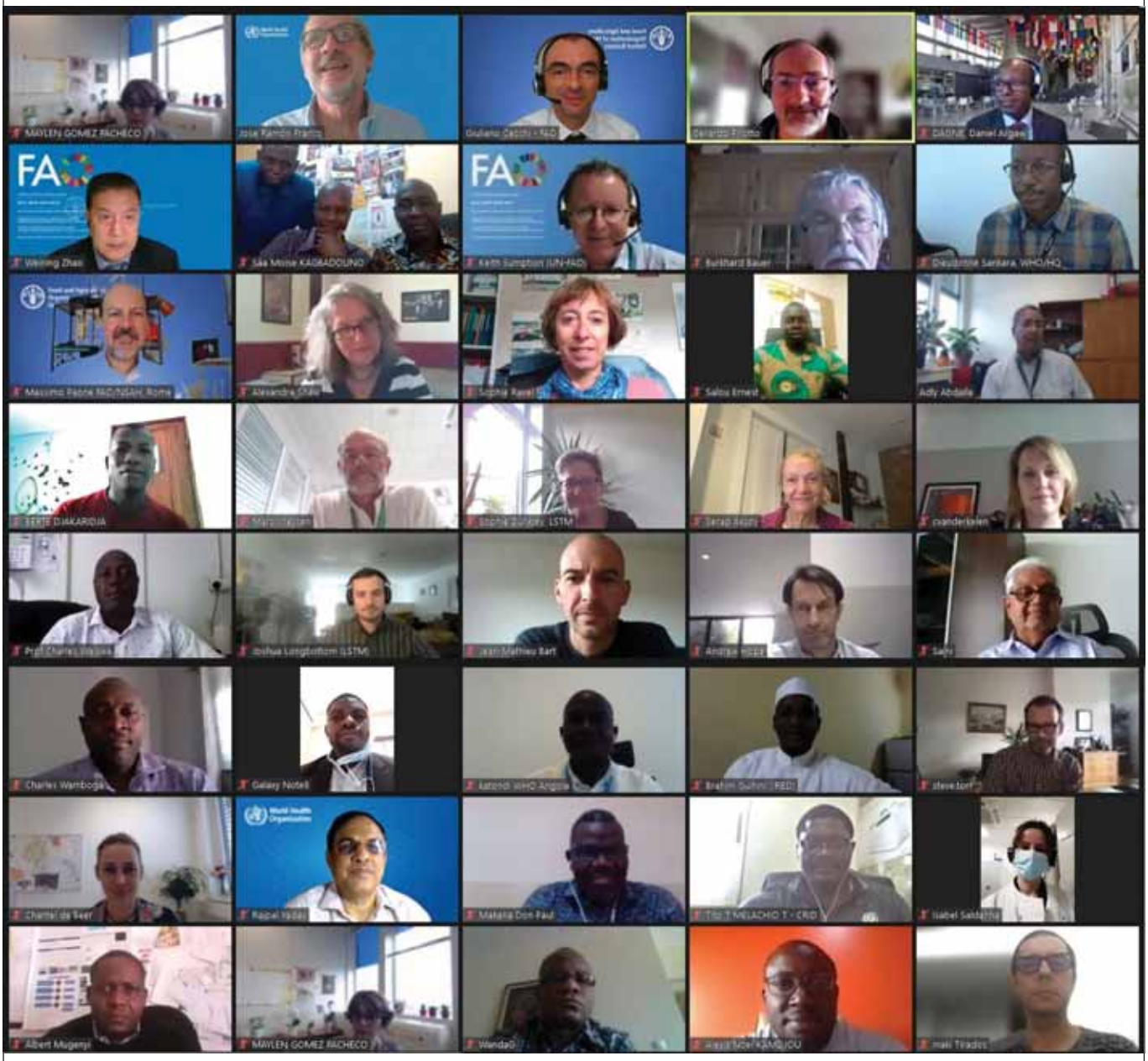
The main purpose of the meeting was to review tsetse control tools, activities and their contribution to the control and elimination of gHAT and the monitoring thereof. Metrics for the estimation of the impact and coverage of vector control in space and time were discussed in an effort to improve and harmonize reporting and monitoring. The main gaps and research needs were addressed, with a view to improving existing tools. Tsetse control activities in the context of gHAT elimination were also discussed in the broader framework of One Health, and in particular in relation to the control of animal trypanosomosis (Diall *et al.*, 2017).

This meeting is framed in the WHO network for HAT elimination and it was organized with the support of, and hosted by the Food and Agriculture Organization of the United Nations (FAO) within the framework of PAAT. Participants included health officials from gHAT endemic countries, research and academic institutions, international organizations and the private sector. The present one was the first meeting of the WHO network for HAT elimination that focused specifically on vector-control.

OPENING REMARKS

The meeting was opened by Keith Sumption, Chief Veterinary Officer, Leader of the FAO Animal Health Programme and Chief of the Joint FAO/WHO Centre (CODEX Food Standards and Zoonotic Diseases), who welcomed participants on behalf of the Animal Production and Health Division of FAO (Figure 1). In his opening remarks he pointed out that FAO has long recognized the severity of the burden of zoonotic diseases, and the need to tackle them through a "One-Health" approach. To promote this approach, FAO, WHO and the World Organisation for

Figure 1
Meeting group photo.



Source: Authors.

Animal Health (OIE) have joined forces in the "Tripartite", and FAO and WHO have established a Joint Centre. Mr Sumption stressed that African trypanosomosis affects humans, livestock, wildlife and the environment at large, and therefore actions aimed at tackling the problem must be rooted in "One Health". He recalled that the Programme Against African Trypanosomosis (PAAT), created in 1997, was an early example of multiagency collaboration to promote "One Health", as it brought together FAO, WHO, the International Atomic Energy Agency (IAEA)

and the African Union (AU), and advocated for coordinated actions at the human-animal-environment interface. Mr Sumption stressed that the present meeting was the latest example of the long-standing and fruitful partnership between FAO and WHO within PAAT, and that FAO remains committed to supporting and collaborating closely with WHO in the elimination of sleeping sickness.

Daniel Argaw Dagne, Coordinator of the Prevention, Treatment and Care Unit, gave the opening remarks on behalf of the Department of Control of Neglected Tropical Diseases of WHO. He stressed the WHO role of coordination of stakeholders involved in the elimination of HAT, and the framework provided by the WHO network for HAT elimination. He also acknowledged the support of FAO in the organization of this meeting, and FAO's continued efforts to promote inter-UN collaboration and collaboration with the African Union (AU) through PAAT. He also highlighted the role of the Tripartite (WHO-FAO-OIE) in promoting the One-Health approach, and the contribution that vector control can play in this context. Indeed, innovative effort to scale up interventions against NTDs at the country level are encouraged within the new WHO road map 2021–2030. The road map rests on three pillars: accelerating programmatic actions, intensifying cross-cutting approaches, and changing the operating model and culture to facilitate country ownership. All these are in line with the promotion of cross-cutting and multisectoral collaboration as exemplified by the One-Health approach.

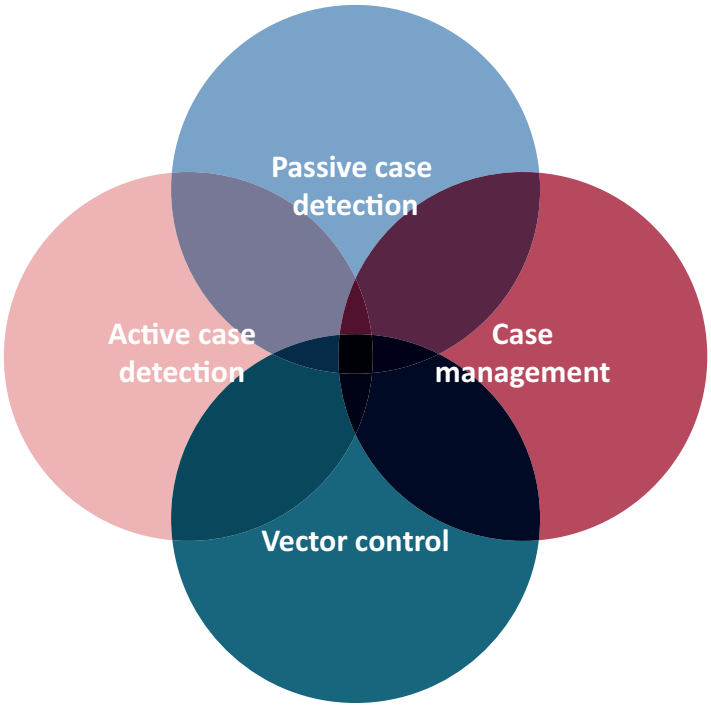
Weining Zhao, FAO Senior Animal Health Officer, gave the opening remarks on behalf of PAAT. He welcomed this important meeting held in the framework of the WHO network for HAT elimination and hosted by FAO. Mr Zhao summarized the main purpose of the meeting, and stressed the role PAAT continues to play in providing a forum for multiagency and multistakeholder consultation in the field of African trypanosomosis control.

Gambiense Human African trypanosomiasis elimination: an overview of progress status, prospects and role of vector control

Opening the technical sessions of the meeting, WHO provided an overview of progress status of gHAT elimination, its prospects and the role of vector control.

In 2012, WHO developed a road map on NTDs (WHO, 2012) that targeted the elimination of HAT as a public health problem by 2020. The goal was subsequently defined quantitatively as "fewer than 2,000 cases reported per year", and "a 90 percent reduction in the areas at moderate or higher risk compared to the 2000–2004 baseline" (Franco *et al.*, 2020). By 2017, with 1 436 HAT cases reported, the first target had already been achieved, with a further reduction in the following years and 663 cases reported in 2020 (Franco *et al.*, 2022). Gambiense HAT accounts for the vast majority of HAT reported cases (that is, 97 percent for the period 2001–2020). For the second indicator – areas where more than one case/10000 people/year

Figure 2
Pillars of the strategy for human African trypanosomiasis elimination.



Source: Authors.

are reported – a reduction of 83 percent was observed between 2000–2004 and 2016–2020, which is slightly below the target of 90 percent reduction. As a result, the overall global target for HAT elimination as a public health problem cannot be considered fully achieved yet.

This substantial progress was achieved against a backdrop of sustained surveillance activities. Between two and three million people were actively screened every year in the period 2000–2020, and the network of health facilities with capacity for HAT diagnosis and treatment was progressively expanded, with 1 798 identified by the latest WHO survey (June 2021) (Franco *et al.*, 2022).

The strategy for HAT control and elimination rests on four pillars: active case detection, passive case detection, case management and vector control (Figure 2). These components are combined and adapted according to the local epidemiological situation.

Recent and ongoing field activities in endemic countries

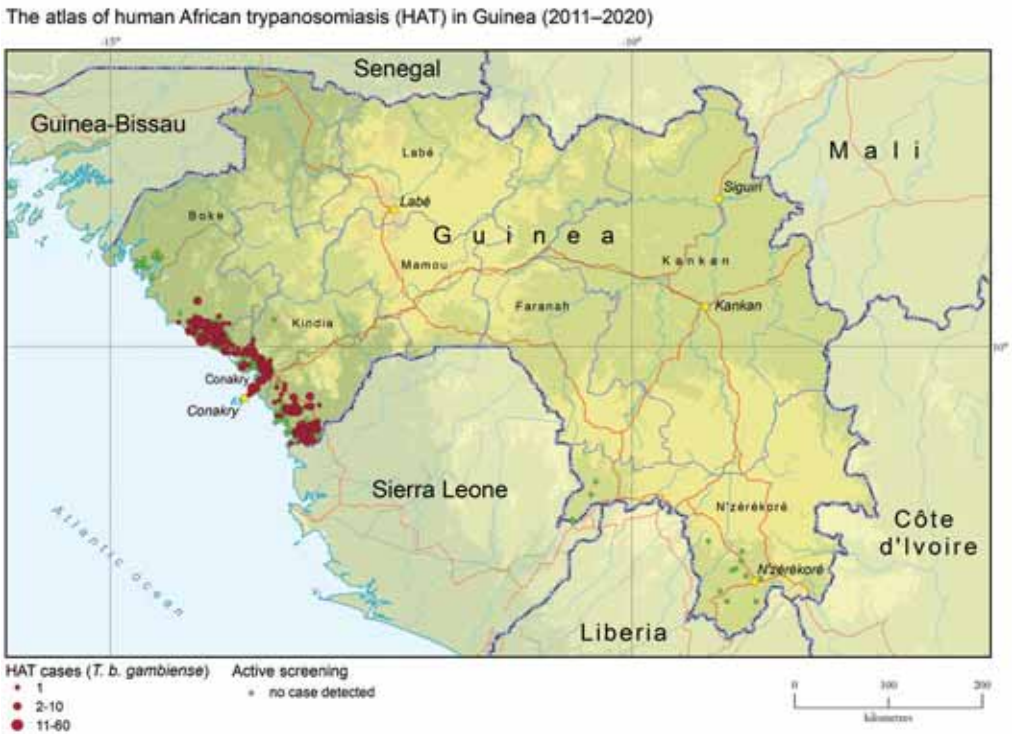
GUINEA

Over the past ten years (2011–2020), Guinea reported an average of approximately 70 cases of gHAT per annum. A peak of 139 cases was observed in 2017 following the reinforcement of active screening activities after the Ebola epidemic, and 36 cases were reported in 2020. Cases of gHAT in Guinea are reported from the mangrove ecosystems in the coastal region (Figure 3), and in particular from the three foci of Boffa, Dubréka and Forécariah.

In addition to medical activities against gHAT, vector control in Guinea is implemented by the Ministry of Health (National Sleeping Sickness Control Programme - NSSCP), with the engagement of local communities, the technical support of research institutions (the French *Institut de recherche pour le développement* - IRD) and funding from philanthropic organizations (Bill & Melinda Gates Foundation - BMGF). Within the NSSCP there exists a vector control unit, which includes an entomologist,

Figure 3

Human African trypanosomiasis (*T. b. gambiense*) in Guinea. Period: 2011–2020.



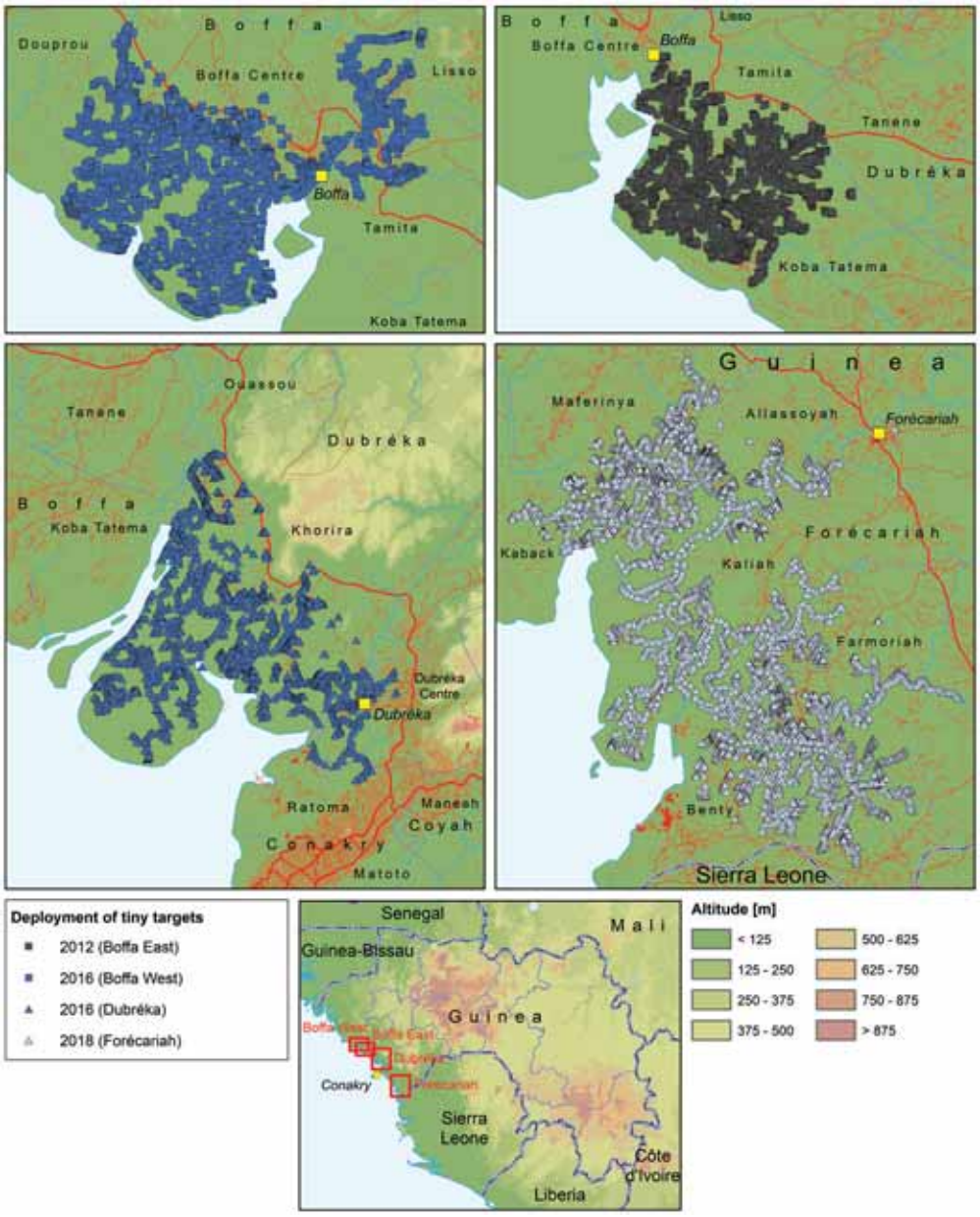
Source: United Nations. 2021. Map of the World [online*] [Cited 26 April 2022] modified with data provided by the WHO atlas of human African trypanosomiasis. **Franco, J. R., Cecchi, G., Paone, M., Diarra, A., Grout, L., Kadima Ebeja, A., Simarro, P. P., Zhao, W. & Argaw, D.** 2022. The elimination of human African trypanosomiasis: Achievements in relation to WHO road map targets for 2020. PLoS neglected tropical diseases, 16(1): e0010047.

* https://www.un.org/geospatial/file/3420/download?token=bZe9T8I9

a geographer and supporting medical staff. Tiny targets are used as vector control tool while biconical traps are used for tsetse monitoring. The vector control unit, in collaboration with local communities and partners, is in charge of the deployment of targets, entomological monitoring and awareness raising activities.

Vector control activities were initiated in 2012 in the eastern part of the Boffa focus, with 4 702 targets deployed (Figure 4). These were reduced to 3 681 in 2019.

Figure 4
Locations of deployment of tiny targets for tsetse control in the human African trypanosomiasis foci of Boffa, Dubréka and Forécariah, Guinea. Period: 2012–2018.



Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the National Sleeping Sickness Control Programme in Guinea.

In 2016 the activities were extended to the western part of the Boffa focus and to the Dubréka focus, with 4 406 and 2 313 targets deployed respectively. In 2018 tsetse control was extended to the Forécariah focus, with 5 397 tiny targets deployed.

The deployments of targets normally take place over a period of 65 days, while entomological monitoring is undertaken for periods of 30 days. In the intervention areas reductions in tsetse fly densities ranged from 80 to 93 percent, with tsetse densities decreasing from baseline levels of 8-15 flies/trap/day to 1-1.8 flies/trap/day. Reduced tsetse nuisance is reported by the communities, which contributes to their engagement in the control activities.

Vector control is planned to be intensified in the zones where relatively high tsetse densities persist, including the use of a novel vector control tool currently being tested (X-target). Activities are also expected to be expanded to some areas that are not presently covered. Reactive vector control is being considered (targeting zones where new HAT cases emerge). Scaling down of vector control is envisaged in the zones where tsetse densities have been substantially reduced, and where HAT cases have not been reported for five years. Funding for sustaining vector control activities is expected to continue to be provided by philanthropic organizations, as well as by the national government and possibly other resource partners, even though the sustainability of funding is acknowledged as a challenge. Other recognized challenges are the acquisition of the tiny targets and the need for a deeper and sustainable engagement of local communities.

CÔTE D'IVOIRE

In the period 2011–2020, Côte d'Ivoire reported an average of four cases of gHAT per annum. A progressive reduction was observed over that period, with an average of seven cases/year in 2011–2015, 1.2 cases in 2016–2020, and no cases reported in 2020. Two districts are presently identified as being gHAT endemic: Bouaflé and Sinfra (Figure 5). In 2020, Côte d'Ivoire was the second country to be validated by WHO as having eliminated HAT as a public health problem at the national level. Following this achievement, surveillance and control activities continue, in an effort to reach the next objective of elimination of disease transmission, which Côte d'Ivoire is targeting for 2025. In this context, passive surveillance is being reinforced, enabling one case of gHAT to be detected in August 2021 in the focus of Sinfra.

In Côte d'Ivoire tsetse flies are widely distributed, and they are present well beyond the gHAT endemic foci. Trypanosomosis is also widespread in domestic animals. Because of this, studies have been conducted across the country to map the occurrence of tsetse species, and also to explore the possible animal reservoir of *T. b. gambiense* (for example in free-range pigs). These studies aim to take a broader look at the risk of gHAT transmission at the national level.

Vector control activities in Côte d'Ivoire are coordinated by the Ministry of Health (National Sleeping Sickness Elimination Programme - NSSEP), and planned and implemented by the *Institut Pierre Richet* (IPR), a research institution operating within the National Institute of Public Health and focusing on vector-borne diseases. Technical support is provided by IRD, the *Centre international de recherche-développement sur l'élevage en zone subhumide* (CIRDES) and the French *Centre de coopération internationale en recherche agronomique pour le développement* (CIRAD). Funding is provided by BMGF. Tiny targets

Figure 5
Human African trypanosomiasis (*T. b. gambiense*) in Côte d'Ivoire. Period: 2011–2020.

Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the WHO atlas of human African trypanosomiasis. **Franco, J. R., Cecchi, G., Paone, M., Diarra, A., Grout, L., Kadima Ebeja, A., Simarro, P. P., Zhao, W. & Argaw, D.** 2022. The elimination of human African trypanosomiasis: Achievements in relation to WHO road map targets for 2020. PLoS neglected tropical diseases, 16(1): e0010047.

(50 × 70 cm) impregnated with deltamethrin (300 mg/m^2 of tissue) (Figure 6) are used to control tsetse flies, and in particular *Glossina (G.) palpalis palpalis* – the main vector of gHAT in Côte d'Ivoire.

Vector control activities were initiated in February 2016 in the focus of Bonon, an area of 130 km^2 in the Bouaflé Department (Figure 7). By February 2018, the area was covered by approximately 2 000 targets (that is, 16 targets/km^2). This number of target was maintained until February 2021, and then reduced to 747. In the focus of Sinfra (120 km^2), vector control started in June 2017, with 736 targets deployed in selected areas (that is, areas at higher risk of gHAT transmission). This intensity of vector control was maintained until August 2020, when the number of targets was scaled down to 457. Entomological monitoring is conducted every three months in the intervention areas, and since 2015 reactive vector control has been carried out in the areas where new cases of gHAT are detected.

Figure 6
Deployment of a tiny target in 2017 in the gambiense HAT focus of Sinfra, Côte d'Ivoire.

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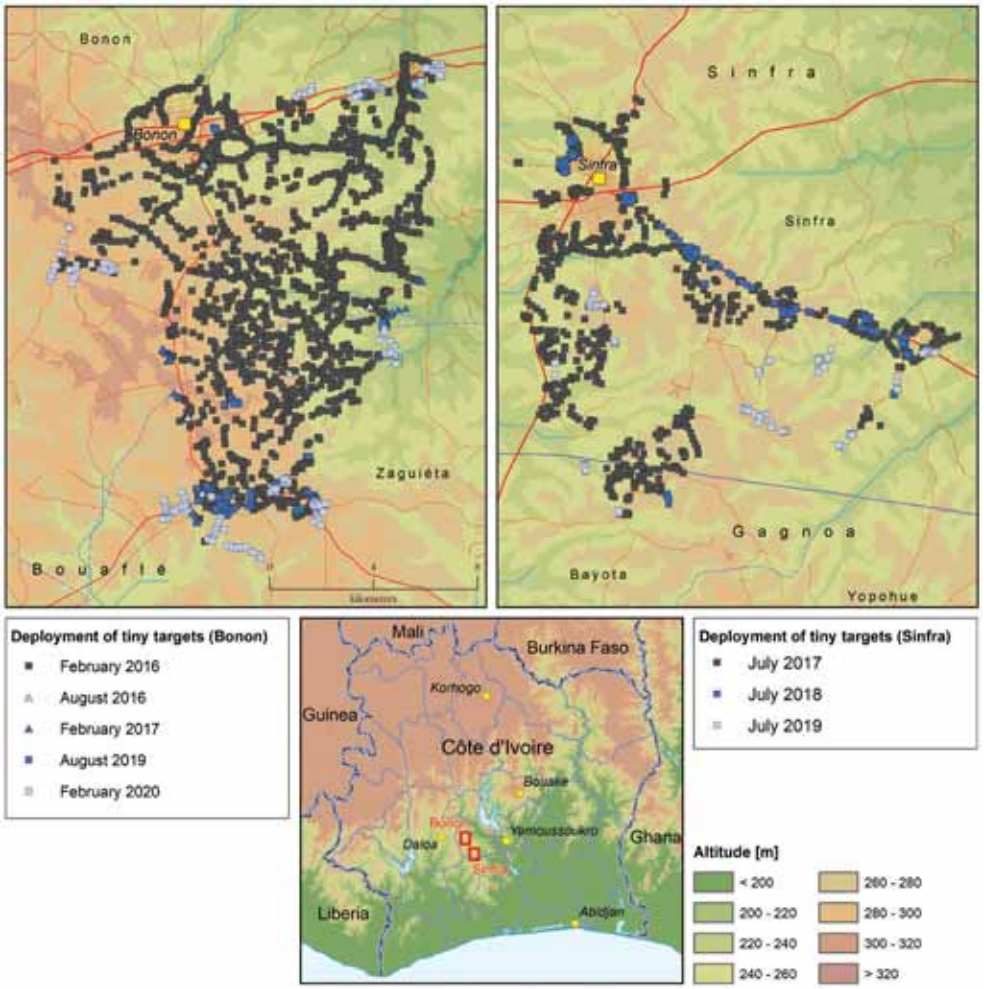
In the intervention areas, reductions in tsetse densities of more than 98 percent were achieved, with a decrease from a baseline of more than 20 flies/trap/day to less than one fly/trap/day in the Bonon focus, and from more than eight flies/trap/day to less than 0.2 flies/trap/day in the Sinfra focus. These achievements, combined with medical surveillance and control activities, have contributed to reducing gHAT transmission in the past few years.

In the future, reinvasion or re-emergence of tsetse populations will threaten the achievements of vector control when activities are interrupted. Efforts will be made to delay tsetse reinvasion and re-emergence in the controlled areas as much as possible, with a view to further reducing the circulation of gHAT, also in the presence of a possible animal reservoir. In this context, vector control activities will be scaled down around sacred forests, whilst barriers against reinvasion will be maintained and entomological monitoring will be intensified at the periphery of the controlled areas. Reactive vector control (that is, targeting the areas where new gHAT cases are detected) is also envisaged to be sustained. Additional funding will be needed to sustain the achievements of vector control, with current funds ending in 2022.

Figure 7
Locations of deployment of tiny targets for tsetse control in the human African trypanosomiasis foci of Bonon and Sinfra, Côte d'Ivoire. Period: 2016–2020.



Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the Institut Pierre Richet/National Sleeping Sickness Elimination Programme in Côte d'Ivoire.

CAMEROON

In the period 2011–2020, Cameroon reported a fairly stable average of eight cases of gHAT per annum. In the past few years, the vast majority of cases were reported from the southern region, especially from the Campo focus next to the frontier with Equatorial Guinea, but also from the Bipindi focus. A few cases were also reported in the eastern region (Figure 8).

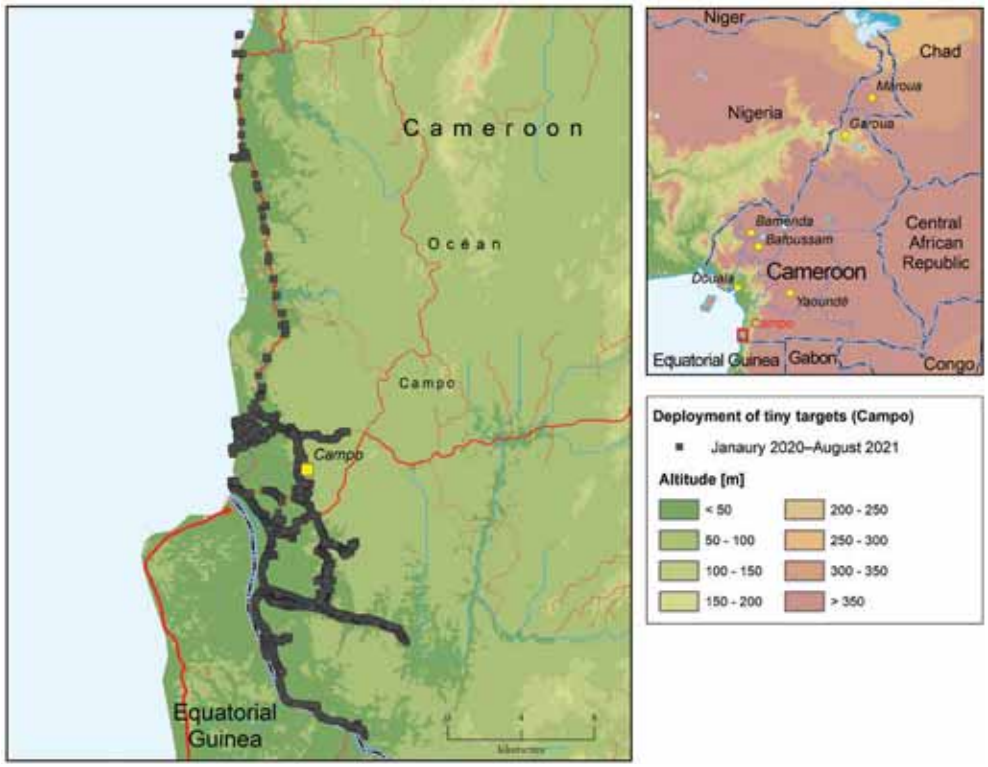
Vector control activities against gHAT in Cameroon are coordinated and supported by the Ministry of Health (NSSCP), and mainly implemented by research institutions, in particular the Centre for Research in Infectious Diseases (CRID) in collaboration with the Liverpool School of Tropical Medicine (LSTM) but also IRD and the University of Dschang. In particular, CRID conducted two baseline entomological surveys in the Campo focus using pyramidal traps (December 2018

Figure 8
Human African trypanosomiasis (*T. b. gambiense*) in Cameroon. Period: 2011–2020.

Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the WHO atlas of human African trypanosomiasis. **Franco, J. R., Cecchi, G., Paone, M., Diarra, A., Grout, L., Kadima Ebeja, A., Simarro, P. P., Zhao, W. & Argaw, D.** 2022. The elimination of human African trypanosomiasis: Achievements in relation to WHO road map targets for 2020. PLoS neglected tropical diseases, 16(1): e0010047.

and July 2019). Thereafter, in January 2020, a pilot study on tsetse control using tiny targets was initiated in the area. The targets were provided by the LSTM, and they were deployed in the southern and western part of the focus. Targets are replaced every six months, and entomological monitoring is also carried out at six-month intervals. An average of 1 700 targets were deployed at each of the four rounds

Figure 9
Locations of deployment of tiny targets for tsetse control in the human African trypanosomiasis focus of Campo, Cameroon. Period: January 2020–August 2021.



Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the Partnership for Increasing the Impact of Vector Control/Centre for Research in Infectious Diseases/National Sleeping Sickness Control Programme in Cameroon.

completed so far (from January 2020 to August 2021). The locations of deployment are shown in Figure 9. Up to the present stage of the pilot study, reductions of 70 percent in tsetse densities and 90 percent in tsetse infection rates were observed.

There is a hope that vector control activities can be intensified in Campo, with a view towards covering the entire focus, and not only the areas at higher risk. Resource mobilization efforts are ongoing to this end. Owing to competing health priorities, country ownership of the activities is a challenge, but advocacy is being promoted to mobilize national resources, alongside possible external funding.

CHAD

Over the past ten years (2011–2020), Chad reported approximately 95 cases of gHAT per annum, with a sizable and fairly steady decrease from 276 cases in 2011 to 17 cases in 2020. Over this period, cases were reported from three foci in the south-western part of the country: Mandoul, Maro and Moissala (Figure 10).

Vector control activities against gHAT are implemented by a research institute under the Ministry of Livestock and Animal Resources (i.e. *Institut de recherche en élevage pour le développement* - IRED), in partnership with the Ministry of Health (NSSCP). Insecticide-impregnated tiny targets are used as vector control tool, and

Figure 10
Human African trypanosomiasis (*T. b. gambiense*) in Chad. Period: 2011–2020.

Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the WHO atlas of human African trypanosomiasis. **Franco, J. R., Cecchi, G., Paone, M., Diarra, A., Grout, L., Kadima Ebeja, A., Simarro, P. P., Zhao, W. & Argaw, D.** 2022. The elimination of human African trypanosomiasis: Achievements in relation to WHO road map targets for 2020. PLoS neglected tropical diseases, 16(1): e0010047.
Final boundary between the Sudan and South Sudan has not yet been determined.

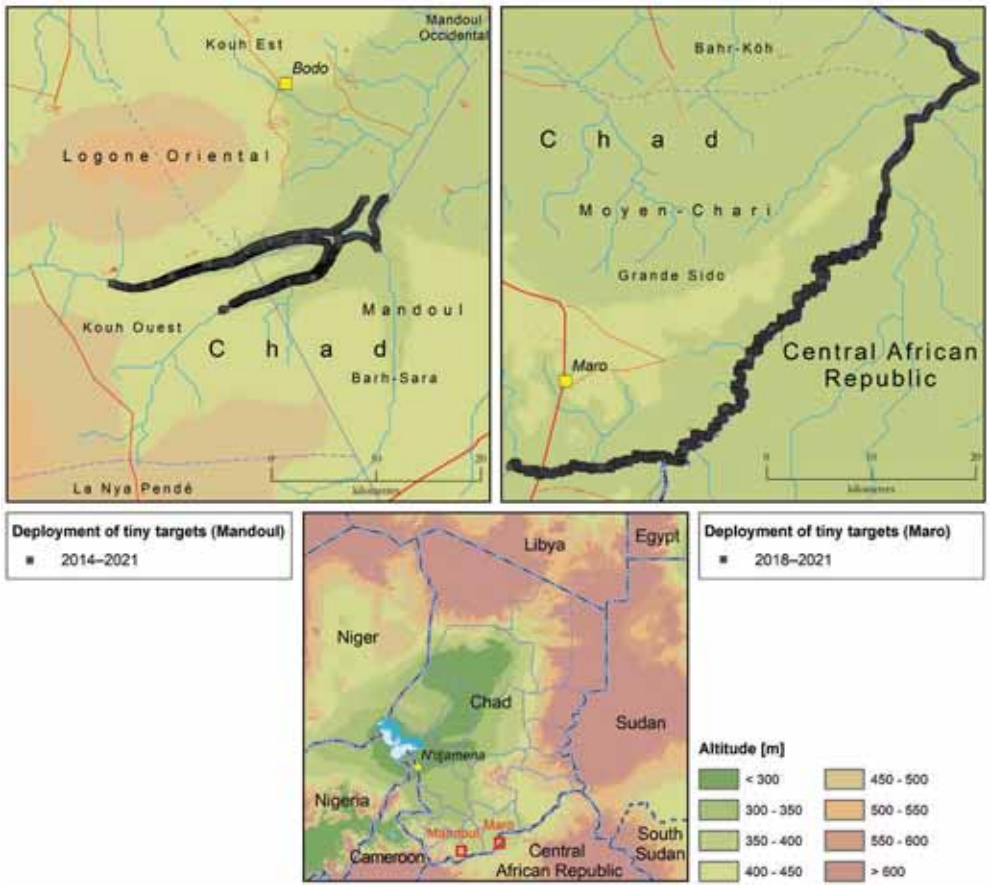
biconical traps are used for entomological monitoring. The activities are technically supported by IRD, CIRDES and LSTM, and funded by BMGF. Vector control is presently targeted at the two foci that have reported the highest number of cases over the past few years (Mandoul and Maro). An IAEA-supported project is also

being implemented to assess the feasibility of using the sterile insect technique (SIT) to contribute to the elimination of tsetse flies in the Mandoul focus.

Vector control activities based on tiny targets were initiated in 2014 in the Mandoul focus, and in 2018 they were extended to the Maro focus (Figure 11). Trap deployments are carried out over periods of two to three weeks, and they normally take place in January-March. *G. fuscipes fuscipes* is the vector of gHAT targeted by vector control activities in Chad. In the Mandoul focus, an area of 7 200 km^2 is considered to be covered by tsetse control activities, with a reduction in tsetse densities from 0.02 flies/trap/day in 2014 to 0 from 2017 onwards. In the Maro focus, 2 000 km^2 are covered, with a reduction in tsetse densities from 1.67 flies/trap/day in 2018 to 0.58 in 2021. Reduced tsetse nuisance is reported by the communities, and a contribution to the reduction in gHAT transmission is reported.

There is a desire to intensify vector control activities in the foci of Mandoul and Maro to contribute to the interruption of gHAT transmission, and efforts are ongoing to mobilize the necessary resources from the national government as well as

Figure 11
Locations of deployment of tiny targets for tsetse control in the human African trypanosomiasis foci of Mandoul and Maro, Chad. Period: 2014–2021.



Source: UN 2021 modified with data provided by the *Institut de Recherches en Élevage pour le Développement*/National Sleeping Sickness Control Programme in Chad.

present and new resource partners. The sustainability of activities and achievements is considered a challenge, as they presently rely on one externally funded project. Other challenges include the need to strengthen government support and to implement transboundary vector control activities, as the Maro focus lies at the boundary between Chad and the Central African Republic.

UGANDA

Over the past ten years (2011–2020), Uganda reported approximately nine cases of gHAT per annum, with a substantial and sustained decrease from 44 cases in 2011 to one cases in 2020. Over this period, most cases were reported from five districts in the north-western part of the country – Moyo, Yumbé, Adjumani, Arua and Koboko (Figure 12).

Figure 12
Human African trypanosomiasis (*T. b. gambiense*) in Uganda. Period: 2011–2020.

Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the WHO atlas of human African trypanosomiasis. **Franco, J. R., Cecchi, G., Paone, M., Diarra, A., Grout, L., Kadima Ebeja, A., Simarro, P. P., Zhao, W. & Argaw, D.** 2022. The elimination of human African trypanosomiasis: Achievements in relation to WHO road map targets for 2020. PLoS neglected tropical diseases, 16(1): e0010047.

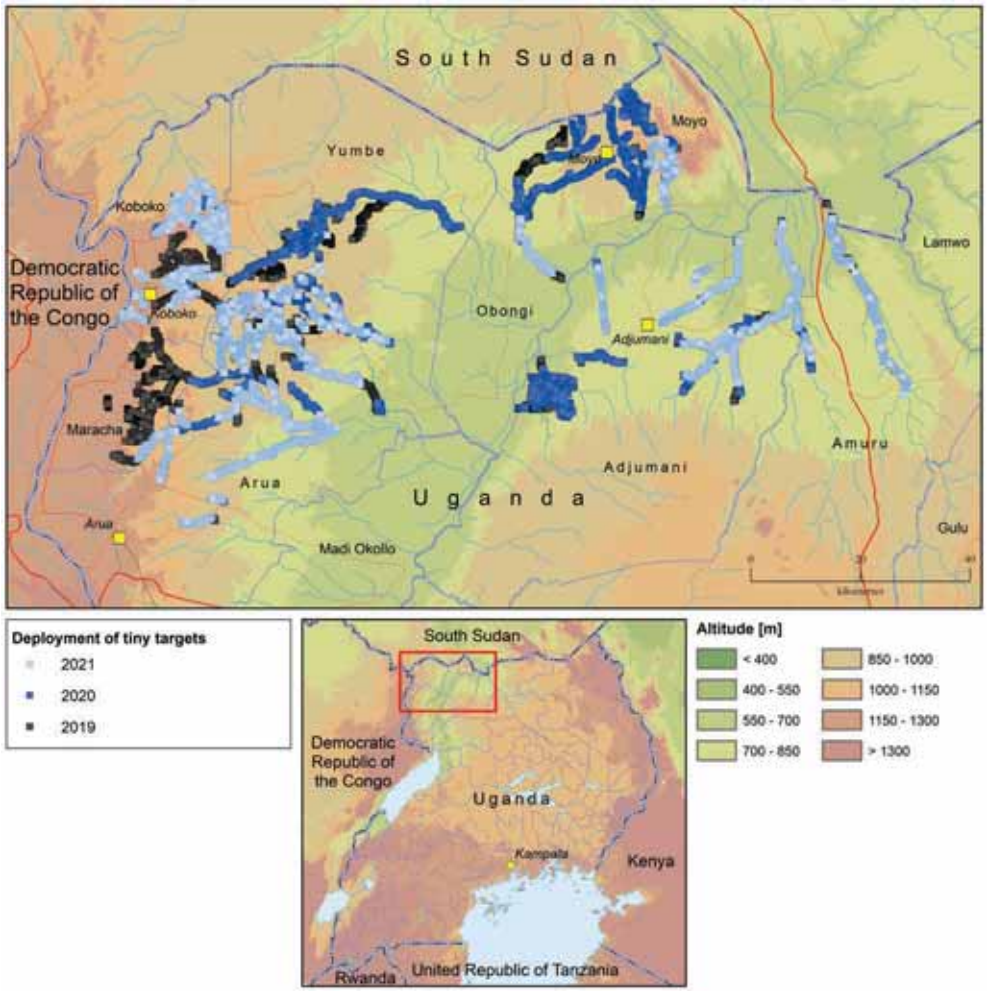
Vector control activities against gHAT in Uganda are led by the Uganda Trypanosomiasis Control Council (UTCC) and its secretariat, the Coordinating Office for Control of Trypanosomiasis in Uganda (COCTU), in collaboration with the Ministry of Agriculture Animal Industry and Fisheries (Entomology Department) and the Ministry of Health (NSSCP). The activities are technically supported by district local governments, the Uganda Wildlife Authority (UWA), the National Livestock Resources Research Institute (NaLIRRI), Gulu and Makerere Universities and international partners (LSTM, University of Edinburgh, FAO, IAEA). Funding is provided mainly by external partner (BMGF), and to a limited extent by the national government through its support to local governments (districts).

Insecticide-impregnated tiny targets are the main tool used to control tsetse in gHAT endemic areas, and pyramidal traps are used for entomological monitoring. Other vector control tools used include insecticide treat cattle, where livestock are used as live bait, and targeted bush clearance.

Vector control activities based on tiny targets in Uganda were initiated with trials in 2012, and with large-scale interventions in 2014. At their peak, the interventions concerned seven districts (Maracha, Koboko, Arua, Yumbe, Moyo, Adjumani and Amuru) (Figure 13). By 2019, given the very low number of gHAT cases, progressive scale back and a shift toward reactive vector control became the focus. As an example of reactive vector control, in 2020 two cases were detected in areas not covered by vector control activities (Moyo and Yumbe districts), including one transboundary case from South Sudan. Baseline tsetse surveys were subsequently carried out, and tiny targets were deployed in Yumbe.

The impact of vector control on tsetse densities is monitored through a network of 138 sentinel traps, which are located both inside the intervention area and outside as a control. A reduction of 90 percent in fly densities was reported from the main intervention block, where activities were initiated in 2014, while a 70 percent reduction was observed in the areas where interventions were extended into a second stage. Current external funding for vector control activities against gHAT using tiny targets will end in December 2020, and sustainability after that date is not guaranteed. The national and local governments are being engaged to develop a sustainability plan, but securing their commitment and funding is going to be challenging because of the very low number of gHAT cases. Other challenges include refugees from South Sudan and insecurity. In particular, the latter hinders tsetse monitoring and control in certain areas, which could therefore represent a source of re-infestation.

Figure 13
Locations of deployment of tiny targets for tsetse control in the human African trypanosomiasis foci in north-western Uganda. Period: 2019–2021.



Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the Liverpool School of Tropical Medicine/ Coordinating Office for Control of Trypanosomiasis in Uganda/National Sleeping Sickness Control Programme in Uganda.

DEMOCRATIC REPUBLIC OF THE CONGO

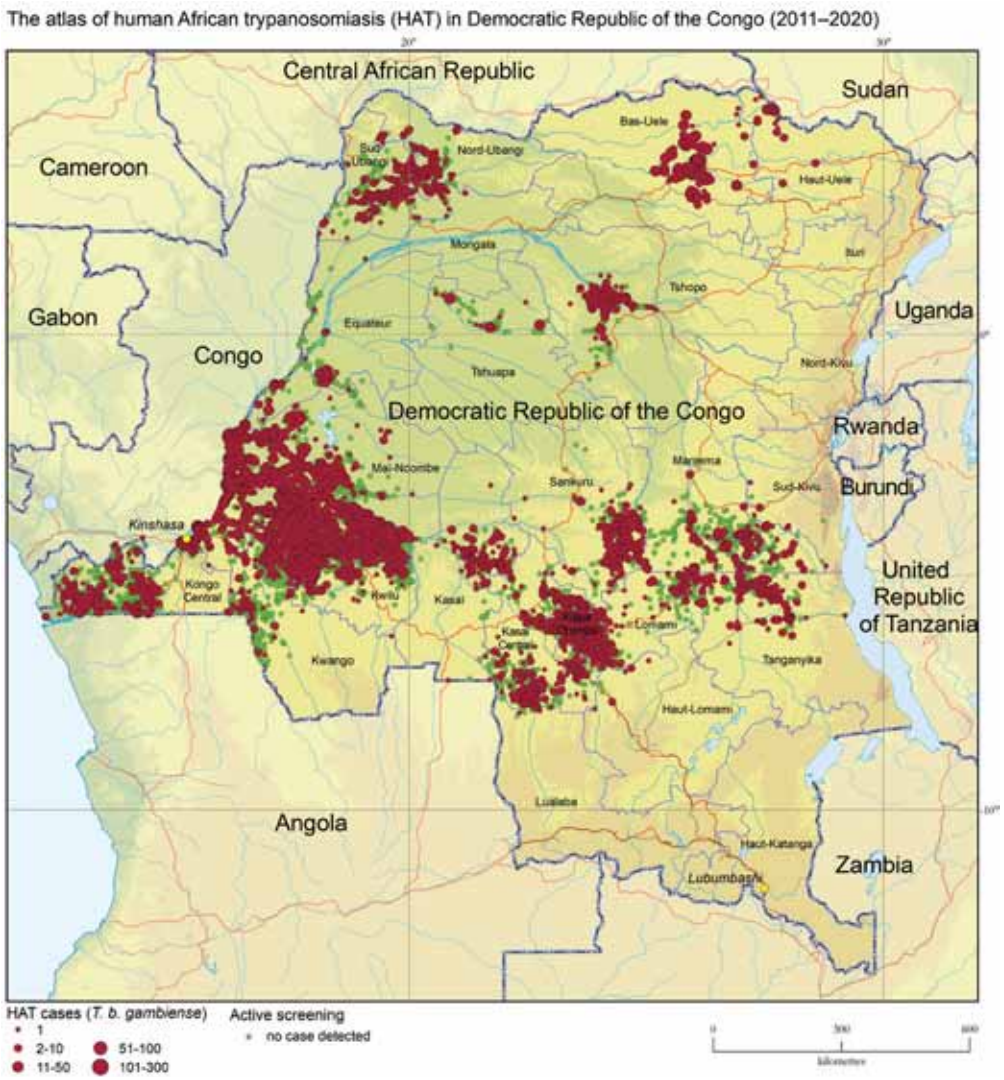
In the period 2011–2020 cases of gHAT in the Democratic Republic of Congo declined substantially and steadily, with over 5 500 cases per year being reported in 2011–2013, 613 cases in 2019 and 395 in 2020. The former province of Bandundu reported the highest number of cases (Figure 14). The number of cases reported in 2020 is believed to have been affected by a reduction in case finding due to the COVID-19 pandemic. In general, the epidemiological situation at the country level is well understood, even though a few grey areas in the northern part of the country do exist.

Vector control activities against gHAT in the Democratic Republic of the Congo are carried out by the Ministry of Health (NSSCP). At the NSSCP central level, a vector control unit exists. Units also exist at the level of provincial coordination, with a focus being placed on Bandundu Nord and Bandundu Sud. At the operational field level,

capacity was also developed in the health zones involved in vector control, where community health workers were trained in the intervention villages. Partner institutions include the Institute of Tropical Medicine (ITM) in Antwerp (Belgium), LSTM, with funding provided by BMGF, the Belgian Government, and the national government.

The tiny targets are used for tsetse control, and locally produced pyramidal traps are used for entomological monitoring. Two approaches are used for the deployment of targets: a vertical one, focusing on the many waterways and rivers, and a community-based/horizontal one, focusing on the village level. Targets are replaced every six months.

Figure 14
Human African trypanosomiasis (*T. b. gambiense*) in the Democratic Republic of the Congo. Period: 2011–2020.



Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the WHO atlas of human African trypanosomiasis. **Franco, J. R., Cecchi, G., Paone, M., Diarra, A., Grout, L., Kadima Ebeja, A., Simarro, P. P., Zhao, W. & Argaw, D.** 2022. The elimination of human African trypanosomiasis: Achievements in relation to WHO road map targets for 2020. PLoS neglected tropical diseases, 16(1): e0010047.

Vector control activities initially focused on three pilot health zones (Yasa Bonga, Masi Manimba, and Kwamouth East) with an area of 3 000 km^2 covered by the end of 2018. These health zones are located in Kwilu and Mai-Ndombe provinces, both of which were part of the former Bandundu province. By the end of 2021, a total of 12 health zones is expected to be concerned by vector control activities, covering an area of approximately 12 000 km^2. The WHO atlas of HAT is used to refine the spatial targeting of interventions. In the first deployment in 2021, 25 400 tiny targets were used. With a further extension of the targeted areas in the second deployment, an overall total of 54 000 tiny targets is expected to be used in 2021. Efforts are being made to progressively strengthen community participation, with the community-based/horizontal approach being expanded from 12 villages in 2018 (Yasa Bonga Health Zone) to 93 villages (in Yasa Bonga, Masi Manimba, Bandundu and Kikongo health zones). In 2021, a total of 27 900 targets are expected to be deployed through community participation, with 150 targets per village and per deployment being used.

The impact of vector control on tsetse densities is monitored every six months, with an overall average reduction of 85%.

In terms of perspectives, vector control against gHAT is envisaged to be intensified, by focusing on high transmission health zones. Funding is expected to be provided by the present resource partners (BMGF and Belgian Government) and the national government. Efforts will be made to further promote country ownership, with the enhancement of NSSCP competencies at the central, provincial and local (operational) levels. Expected challenges include funding, political instability (for example in the province of Kasaï Oriental), and difficulties in accessibility and communication.

ANGOLA

Over the past ten years (2011–2020), Angola reported an average of approximately 54 cases of gHAT per annum, with a general trend towards reduction (an average of 73 cases per annum in the period 2011–2015 and 36 in the period 2015–2020). However, at the date of the present meeting, 170 cases had already been reported in 2021. Out of the 18 provinces in Angola, tsetse flies are present in 14 and seven of them are endemic for gHAT. The latter are located in the north-western part of the country, and most cases are reported from the provinces of Bengo, Cuanza Norte and Uige (Figure 15).

Vector control activities against gHAT in Angola are carried out by the Ministry of Health, and in particular by the *Instituto de Combate e Controlo das Tripanossomíases* (ICCT). Integrated vector control activities against tsetse and mosquitoes are also being introduced in collaboration with the malaria programme, and in particular in collaboration with technical staff at the level of health districts. Collaboration is being pursued with the Ministry of Agriculture, and in particular with the Institutes of veterinary service and of veterinary investigation, with a view towards tackling the One-Health dimensions of disease transmission (for example trypanosomal infections in pigs). Supporting institutions include the Angolan Armed Forces and a national non-governmental organization (Fundanga). Funding for vector control activities in Angola is solely provided by the national government.

Figure 15
Human African trypanosomiasis (*T. b. gambiense*) in Angola. Period: 2011–2020.

Source: United Nations. 2021. Map of the World [online] [Cited 26 April 2022] modified with data provided by the WHO atlas of human African trypanosomiasis. **Franco, J. R., Cecchi, G., Paone, M., Diarra, A., Grout, L., Kadima Ebeja, A., Simarro, P. P., Zhao, W. & Argaw, D.** 2022. The elimination of human African trypanosomiasis: Achievements in relation to WHO road map targets for 2020. PLoS neglected tropical diseases, 16(1): e0010047.

Impregnated pyramidal traps and ground spraying are the two tools used in Angola to control tsetse flies in gHAT endemic areas. Traps are deployed first, and tsetse are collected after approximately one week. Where high densities of flies are detected, ground spraying follows. Local communities, and where present the armed forces, are engaged in the field activities, both for the deployment of the traps and the collection of captured tsetse. The activities of the ICCT teams normally take place over a period of 20 to 30 days. Thereafter, traps are maintained and checked by local communities for periods of up to six months.

The impact of vector control on tsetse densities is patchy, and comprehensive data are lacking. However, a sizable and positive impact is reported in some zones, while in other areas more limited and short-lived impacts are reported.

The ICCT hopes to intensify vector control in the gHAT endemic areas and to extend it to non-endemic areas, but the mobilization of additional funding from the national government is expected to be challenging. It is also hoped to introduce new control tools (tiny targets) and to strengthen entomological capacity, including for xenomonitoring.

LARGE-SCALE VECTOR CONTROL INTERVENTIONS IN THE FRAMEWORK OF THE PAN-AFRICAN TSETSE AND TRYPANOSOMIASIS ERADICATION CAMPAIGN

The Pan-African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) is an AU initiative based on a decision by the African Heads of State and Government. Its strategy advocates for vector eradication through a phased, conditional, area-wide and sustained approach. According to the PATTEC Coordination Office, the current status of implementation of the initiative includes two countries freed from tsetse (i.e. Botswana and Namibia), 17 countries with projects at different levels of intensity, coverage and consistency of vector control (i.e. Angola, Democratic Republic of the Congo, Cote d'Ivoire, Burkina Faso, Ghana, Kenya, Ethiopia, Mali, Uganda, United Republic of Tanzania, Zambia, Sudan, Senegal, Zimbabwe, Nigeria, Chad and Guinea), 15 countries at different levels of vector control programme initiation (i.e. Mozambique, South Africa, Eswatini, Cameroon, Central African Republic, South Sudan, Congo, Benin, Niger, Togo, Equatorial Guinea, Gabon, Malawi, Burundi, Rwanda) and four countries that have not initiated action on vector control (i.e. Liberia, Sierra Leone, Guinea Bissau and the Gambia).

Success stories are provided by the two countries that have freed themselves from tsetse flies, and from some of countries with ongoing initiatives. However, documentation is generally scanty, while specific studies to measure impact are required. In general, impacts attributed to vector interventions include improved livestock and crop productivity, improved livelihoods and incomes, increased availability of arable land, and improved revenue from tourism. Countries with documentation on all or some of these parameters include Burkina Faso, Ghana, Mali, Ethiopia, Kenya, Uganda, Zimbabwe, Senegal, Botswana, Nigeria, and Zambia. Notably, apart from Uganda, none of these has reported gHAT within the past four years.

Large-scale vector control in gHAT endemic countries is limited. Notable exceptions are the interventions implemented in Burkina Faso, Ghana and Mali between 2009 and 2013 in the framework of a multinational project funded by the African Development Bank. These interventions targeted a total of approximately 80 000 km^2, and achieved various levels of tsetse reduction with varying levels of sustainability (Adam *et al.*, 2013; Percoma *et al.*, 2018).

Tools and approaches

INSECTICIDE-BASED METHODOLOGIES AGAINST TSETSE

In the late 1930s and early 1940s organochlorides (e.g. Dichlorodiphenyltrichloroethane - DDT) started to be used in the control of disease vectors, including tsetse flies (Du Toit, 1947). Pyrethroids (e.g. deltamethrin) were introduced in the 1970s (Mangwiro *et al.*, 1999), and today they remain the main class of insecticides used in tsetse control. Insecticides can be used to kill adult flies either when resting (for example ground or aerial spraying) or feeding (insecticide-treated targets or cattle).

Ground spraying of persistent insecticide was the main control tool used in the 1950s. In the 1970s, the sequential aerosol technique was developed, whereby repeated applications of non-residual insecticide droplets are synchronized with the tsetse life cycle so as to kill emerging flies. Around the same period, it was realized that, as tsetse are attracted to their hosts, odours could be used with traps or targets to enhance their attractiveness to tsetse. Tsetse targets were developed, in particular for savannah tsetse flies, having a blue-black colour combination, horizontal oblong shape and fairly large size ("cow-shaped"). For riverine tsetse, the main vectors of gHAT, more recent research on their responses to visual and olfactory cues led to the development of 'tiny targets'. These are made of a blue square of cloth and a black mesh of equal size, for a total size of 50cm × 25cm. As compared to previous targets, these are considered more effective, cheaper, easier to deploy and, being impregnated with insecticide at the manufacturing stage, they last longer (i.e. 6 months). Tiny targets are currently used to control tsetse in gHAT foci in Uganda, Democratic Republic of Congo, Chad, Côte d'Ivoire, Guinea and Cameroon (Ndung'u *et al.*, 2020).

Cattle treated with insecticide can also be used as live baits, thanks to their natural visual and olfactory attractiveness for tsetse. Thanks to the preferential tsetse feeding behaviour on cattle legs and belly, it was also realized that insecticide could be restricted to these parts for an easier, speedier and cheaper treatment. An additional benefit of this approach is the control of other disease vectors (e.g. mosquitoes).

Livestock protective fences (LPF) are another insecticide-based method to control tsetse. They consist of insecticide treated nets that are deployed around livestock pens, kraals or sties to protect animals from biting and other nuisance flies. In particular, they obstruct the flight routes of insects trying to feed on livestock. The nets are normally 1 m high, made of polyethylene impregnated with deltamethrin. The positive effects of LPF include a reduced transmission of vector-borne livestock diseases, less time and energy spent by animals in evading vector attacks, and an overall increase in livestock production and productivity. One-health benefits due to the reduction of vector-borne human disease (e.g. malaria) have also been reported, although they have not been studied in detail yet. LPF were used against tsetse flies in several studies and pilot projects in such countries as Burkina Faso, Ghana, Kenya and Ethiopia. In particular, a case-control study in a forest area in Ghana showed a significant reduction in tsetse densities and animal trypanosomosis in the village where pigsties were protected by LPF (Bauer *et al.*, 2011).

LPF have not been used as yet in gHAT endemic areas in a deliberate effort to support sleeping sickness control and elimination. However, the ecological settings where they have been used to control animal trypanosomosis are often similar to those found in many gHAT foci. As a result, LPF appears as a potentially useful tool to contribute to the elimination of gHAT, especially where animal trypanosomosis can also be targeted in a One-Health framework. Challenges to the use of LPF include shortcomings in the dissemination and availability of the tool in the field, and the issue of safe disposal of the material after usage.

AREA-WIDE INTEGRATED MANAGEMENT OF TSETSE WITH A STERILE INSECT TECHNIQUE COMPONENT

Integrated pest management (IPM) is an environmentally sensitive approach to pest management that relies on information on the pest's life cycles and ecology. This information is used in combination with available pest control methods to manage the pest damage by the most economical means, with the least possible hazard to people, property, and the environment. The area-wide (AW) approach is one that targets the entire pest population so that, when eliminated, there is no risk of reinvasion.

SIT hinges on the production of a large number of flies and the sterilization and release into the field of males. Sterile males go on to mate with wild females, which then produce no offspring. SIT relative efficiency increases as the tsetse densities lower, and it can therefore be used in an AW-IPM framework after other tools have been used to reduce the tsetse populations. A phased conditional approach (PCA) is recommended by the IAEA in case the use of a SIT component is envisaged. Phase one focuses on stakeholder commitment and training; phase two on the collection of baseline data, feasibility studies and strategy development; phase three is the pre-operational phase and, following an external project review; and phase four is the operational phase.

Starting from the 1980s, SIT field project against tsetse were undertaken in United Republic of Tanzania, Burkina Faso and Nigeria, and in the 1990s AW-IPM with a SIT component was used to eliminate *G. austeni* from the island of Zanzibar. Starting in the 2010s a project, presently ongoing, targeted *G. palpalis gambiensis* in the Niayes area of Senegal.

To date, no SIT operational project ever targeted tsetse in gHAT endemic areas. However, an IAEA technical cooperation project (TCP) was implemented in 2018–2021 in the Mandoul gHAT focus in Chad. The project aimed to explore the feasibility of using a SIT component to eliminate *G. fuscipes* form the area, and thereby contribute to the elimination of gHAT. Project stakeholders and partners include IRED, the Ministry of Health (NSSCP), CIRDES, LSTM, IRD and local communities. Genetic population analysis indicated that, should tsetse be eliminated from the area, the probability of reinvasion from neighbouring zones would be very low, especially if tsetse control in neighbouring areas was undertaken at an early stage. In the framework of the PCA, the project is in the pre-operation phase 3. A source tsetse colony has been identified in Slovakia, where tsetse pupae are expected to be produced and shipped to a field insectarium established in Chad for subsequent field releases. The IAEA TCP is planned to be extended within the new project cycle (2022–2023). During this cycle, the project will remain in the pre-operational phase three, and it will focus on the establishment of a colony of the local strain, mating compatibility and competitiveness studies, development and validation of protocols to irradiate and transport male tsetse pupae, and aerial release trials.

Economics: costs and feasibility

THE COST OF VECTOR CONTROL IN THE CONTEXT OF GHAT ELIMINATION, WITH A FOCUS ON 'TINY TARGETS'

Controlling vectors in the context of gHAT elimination is estimated to cost between a few tens and a few hundreds of USD per year and per km^2 protected, depending on the tool used. Traps and normal-size targets are estimated to cost approximately 200 USD/km^2/year, with tiny targets being less expensive in most settings where gHAT is present. The cost of insecticide-treated cattle ranges from USD 70 to 150 for ten cattle treated monthly/km^2/year, for restricted application and pour-on respectively. Aerial spraying (i.e. sequential aerosol technique) ranges from USD 320 to USD 490/km^2/year. Estimates are all based on actual projects, but comparisons can be difficult, especially between fixed baits (traps/targets) and mobile ones (cattle).

More comparable data are available for recent interventions using tiny targets in Uganda (2012–2013) (Shaw *et al.*, 2015), Chad (2015–2016) (Rayaisse *et al.*, 2020) and Côte d'Ivoire (2016–2017) (Courtin *et al.*, 2022). These studies were based on the analysis of the full economic cost, including shares of vehicles, salaries, and so on. However, research costs were excluded. From the studies it emerged that the cost of tiny targets ranged from USD 67/km^2 protected/year in Chad to 88 in Uganda and 471 in Côte d'Ivoire. The sizable variation in costs between the three studies is due to many factors. Most importantly, the ecotypes hosting tsetse were very different, with riverine swamps in the intervention area in Chad, semi-degraded forest in Côte d'Ivoire, and narrow fringing riverine vegetation in Uganda. Project structure and organization affected items such as staff costs, and price levels differed slightly between countries. As regards the breakdown of costs by category of expenditure, on average across the three projects, specialized equipment accounted for 16 percent, vehicle costs 16 percent, staff salaries 22 percent, field allowances 21 percent, community workers/labour 11 percent, administration 8 percent and consumables 6 percent.

When looking at the issue of cost of vector control tools, it is worth noting that, in addition to the number of km^2 protected, other metrics can be used to apportion costs, such as the number of km^2 treated or the number of people protected. These metrics shed light on different aspects of the interventions, so that providing a set of measures rather than a single metric offers a more holistic view of the issue of cost of vector control.

FEASIBILITY OF COMMUNITY-BASED CONTROL OF TSETSE IN THE DEMOCRATIC REPUBLIC OF THE CONGO

Community-based tsetse control has long been a topic of interest, given the advantages it can potentially afford. In discussing the issue, it is useful to distinguish the "programme-led" approach from the "community-based" approach proper. In the former, community participation supports the project, that is, it is a means to reach the project's ends, while to a large extent the planning of, and decision-making in project activities remains the prerogative of health professionals. In the latter, community participation is a goal in itself, and the objective is to ensure the community takes control of the project. Therefore, in a true "community-based" approach, it

is the professionals who support, and project activities are decided and planned by the community.

Since the 1980s, several examples of community-based tsetse control projects documented the feasibility of the approach, as well as its advantages in terms of enhanced project acceptability, lower costs, community empowerment and improved, or at least non-inferior, effectiveness (Gouteux and Sinda, 1990; Okoth, Kirumira and Kapaata, 1991). However, for the recently developed tiny targets, more limited information is available.

To address this gap, in 2017–2018, a study was undertaken to explore the feasibility of a community-based approach for the use of tiny targets in the Democratic Republic of the Congo (Vander Kelen *et al.*, 2020). The study focused on three endemic villages in the Kwilu Province, where tiny targets were deployed around fishponds. Project activities included the creation of village committees, training, awareness raising, planning, and the assembly and deployment of the tiny targets. Focus group discussions and observations revealed the establishment of functional structures in the community, as well as good knowledge acquisition. However, an excessive and time consuming deployment process and challenges in formal monitoring and reporting were also noted. Overall, the study concluded that a community-based approach to tsetse control using tiny targets in the Democratic Republic of the Congo was feasible, while ongoing research is exploring outstanding questions on the scalability and long-term sustainability of the approach.

VECTOR CONTROL AND GAMBIENSE HAT ELIMINATION: ONE-HEALTH PERSPECTIVES

Since tsetse flies transmit both the human and the animal form of the disease, the One-Health perspective has long been recognized in the fight against trypanosomosis. Indeed, multistakeholder partnerships have been established, from the national to the international level (for example PAAT). However, while fully-fledged One-Health initiatives exist in the control of rHAT (Waiswa and Wangoola, 2019), the concept has received less attention in the gHAT context, and its potential can be considered largely untapped yet. This gap can be ascribed to the fact that livestock are not raised in all gHAT foci, and therefore animal trypanosomosis is not always an issue in these areas. Still, gHAT and animal trypanosomosis often co-exist, and several vector control tools offer opportunities to tackle both. Furthermore, despite the fact that vector control against gHAT has expanded in the last few years, data on the knock-on effects of these activities on animal trypanosomosis are lacking. To fill this knowledge gap, perceptions of livestock keepers could be investigated and epizootic surveys could be carried out in areas where vector control was mainly targeted at gHAT control and elimination. Arguably, more evidence on the effects of public-health-driven interventions on livestock could contribute to advocacy and resource mobilization, especially in areas where gHAT has become a very rare disease. The One-Health approach could also help sustain technical capacities for reactive vector control against gHAT. Finally, vector control against animal trypanosomosis contributes to reducing the risk of the re-introduction or re-emergence of gHAT in historical foci, where surveillance can be weak or absent altogether.

In the field of disease monitoring and epidemiology, analysing trypanosomal infections in tsetse can contribute to elucidating the patterns of transmission at the human-animal interface; as such, xenomonitoring could be useful in the context of

gHAT elimination and the related verification process, while also providing relevant data to manage the problem in livestock.

Another One-Health issue related to vector control and gHAT elimination is the use of tools that are not biodegradable and difficult to dispose of properly (for example insecticide-treated targets, including tiny targets, and LPF). In this context, the development of non-polluting, biodegradable vector control devices would be desirable from a broader environmental health perspective.

Reporting metrics and estimation of the impacts

Endemic countries currently report to WHO on HAT cases, actively and passively screened people, and health facilities providing diagnosis and treatment for HAT. The systematic reporting of this information allows to monitor the progress towards HAT elimination, including the coverage of screening and treatment activities.

At the same time, WHO also receives information from countries on the vector control activities against gHAT. However, data reporting in this area is not systematic nor standardized, and harmonized metrics to estimate the coverage of vector control in space and time and to measure its impacts on tsetse densities have not been developed yet (Franco *et al.*, 2022).

There are several reasons for the heterogeneity in the reporting of vector control activities, and for the differences in the way its coverage is estimated. Differences in tsetse habitat is one of these reasons. For example, in some gHAT foci tsetse are concentrated in the riparian vegetation (for example in Mandoul in Chad or in north-western Uganda). In other foci tsetse are more broadly spread across the landscape (for example in central Côte d'Ivoire). As a result, in the former case, tsetse distribution is normally described as 'one-dimensional'/'linear', while in the latter it is better represented as 'two-dimensional'. These differences in tsetse habitat and distribution influence vector control, most notably in the choice of the locations where tools are deployed, and in turn they also affect indicators of coverage.

Different metrics can be used to estimate the coverage of vector control, including: (i) the treated area (that is, the area where the tool is physically deployed); (ii) the area protected by the deployment of the tool, which can be broader than the area directly treated; and (iii) the population that benefits from vector control in terms of reduced risk of infection. Drainage basins have been proposed as units of analysis in those areas where tsetse distribution and the related vector control are closely associated to the hydrological network. In other cases, administrative units, including units of the health system, were used for planning purposes and the related analysis of coverage. Yet in other instances the envelope containing all tools deployed was used.

Human populations, their movement, and the distribution of gHAT cases also influence the spatial targeting of vector control, and thus have a bearing on the concept of coverage. How the risk of gHAT is defined is also important, in particular in relation to the 'coverage of populations at risk'. A quantitative methodology was developed by WHO to estimate and map the population at risk of gHAT, which enables regular and harmonized global monitoring (Simarro *et al.*, 2015). However, many different approaches to defining and estimating gHAT risk can be conceived, and some of them have been used or tested at the country or local level.

Beyond spatial coverage, vector control should also be monitored in time. Different tools normally require different frequencies of redeployment to maintain their effectiveness, and the total period during which vector control may be sustained can vary greatly. The issues of tsetse reinvasion and population rebound should also be

considered when estimating coverage. In particular, reinvasion pressure normally affects the effectiveness of tsetse control more at the edges of the intervention areas. When vector control activities are discontinued, both reinvasion and population rebound will progressively bring tsetse populations back to baseline levels.

Finally, the impact of vector control should be estimated in terms of number of flies captured and trends in tsetse densities. To the extent possible, harmonized metrics should be used also for monitoring this impact of vector control on tsetse populations.

Notwithstanding the complexities in the studied systems, it seems both feasible and desirable to design harmonized metrics to monitor the coverage and impact of vector control activities against gHAT in space and time. This would improve the overall monitoring of gHAT control activities, and it could also contribute to enhancing the planning and targeting of vector control.

The process of verification of gHAT elimination and the possible role of entomological indicators

THE PROCESS OF VERIFICATION OF GHAT ELIMINATION: AN OVERVIEW

In its 2012 roadmap for NTDs, WHO targeted HAT for elimination as a public health problem by 2020, and the elimination of gHAT transmission by 2030. In the new roadmap launched in 2021, two quantitative global targets were defined for gHAT: (i) 15 countries 'verified' for elimination of transmission; and (ii) zero cases reported. According to the terminology used by the Department of Control of Neglected Tropical Diseases in WHO (WHO/NTD), 'validation' is the process of documenting the elimination of a disease as a public health problem, while for elimination of transmission the process is called 'verification'. For both processes, the country disease status has to be assessed against objective criteria, and the achievement of the goals has to be formalized, including the submission of national dossiers to WHO and their subsequent appraisal.

The WHO HAT-elimination Technical Advisory Group (HAT-e-TAG) was established in 2016 as the main WHO technical consultative body for HAT elimination. The HAT-e-TAG reviews indicators to assess elimination, defines requirements for elimination claims, develops templates for national dossiers, establishes procedures for, and contributes to, the assessment of the dossiers, follows up post-validation or post-verification status, and periodically reviews the overall process of validation and verification in the light of scientific advances and new tools.

In relation to the validation of HAT elimination as a public health problem, the HAT-e-TAG adapted global indicators to the national level. In particular, one quantitative target was defined: 'fewer than one case/10 000 inhabitants/year (averaged over a five-year period) reported from each health district in the country' (WHO, 2020; Franco *et al.*, 2020). This must be complemented an 'adequate' level of HAT control and surveillance at the national level. Furthermore, templates for national validation dossiers were developed for both gHAT and rHAT, including a section on vector control.

As regards the verification of interruption of gHAT transmission, the HAT-e-TAG is presently working on the adaptation of the global indicators to the national level. National indicators will be in line with the 2030 roadmap for NTDs and they will draw on already-developed templates for the validation dossiers. Indicators for the verification of interruption of gHAT transmission could include information on the presence or absence of tsetse flies and their possible infection with *T. b. gambiense*. Existing and perspective tools to detect tsetse and their infections are therefore being considered by the HAT-e-TAG taking into account sensitivity, specificity, availability, cost and overall suitability for the verification process. No easy solutions are available for the verification of elimination of gHAT transmission, and an integrated approach is expected to be required. In developing the approach, a number of challenges will have to be considered, including but not limited to integration in the health systems, viability and funding.

DETECTION OF *T. B. GAMBIENSE* INFECTIONS WITH MOLECULAR TOOLS

The detection of trypanosomes or the diagnosis of the disease they cause relies on parasitological, serological or molecular tools. Molecular diagnostics differ from the serological ones in many ways. In particular, they can demonstrate ongoing infection, as the presence of trypanosomal ribonucleic acid (RNA) indicates the presence of live trypanosomes. However, the sensitivity of molecular diagnosis is highly depended on the sampling, as parasitemia progresses in waves, tissues are not always accessible and require biopsy, and, more generally, the volume and concentration of the sample matter. As compared to parasitological diagnosis, molecular tools have a higher specificity and, crucially, they can distinguish *T. b. gambiense* from different but morphologically similar or identical trypanosomes. Sensitivity is also normally higher, although this is more debated because it can be affected by operational parameters.

As regards the overall feasibility, molecular diagnosis is less easy than other techniques to perform properly, and an additional source of variability in sampling is introduced during extraction and amplification. Also, there is a tendency to report results even under suboptimal operational conditions and, more in general, results require careful interpretation.

Different methods exist for the amplification and detection of nucleic acids, including conventional polymerase chain reaction (PCR), real-time PCR, isothermal amplification and sequencing. In particular, the latter solves all questions around specificity which may affect the other methods. In general, the available formats use DNA, but most are also compatible with RNA.

With the molecular tools presently available, *T. b. gambiense* is detected through progressive determination. First, the sub-genus *Trypanozoon*, to which *T. b. gambiense* belongs, is detected through sensitive tools based on conserved multicopy genes that are shared among all *Trypanozoon*. These are available for both DNA and RNA. Then, *T. b. gambiense* type I specific diagnosis can be used, either to exclude atypical Trypanozoon infections in humans (for example *T. b. gambiense* type II, *T. evansi* and *T. b. brucei*) or to detect infections in non-human animals or vectors. TgsGP is the main target gene at this step. TgsGP truly defines *T. b. gambiense* type I as it codes for human serum resistance (Capewell *et al.*, 2013). Conventional PCR, SYBR and probe based qPCR are available formats for TgsGP, even though at different levels of validation. Loop mediated isothermal amplification (LAMP) and other formats could also be used.

Sensitivity of *T. b. gambiense* detection can be increased by increasing the volume of the clinical sample, by preparing concentrated extracts or by improving the stability of isolated nucleic acids. However, given the low sensitivity of methods based on TgsGP, research is ongoing to discover and validate novel markers. To this end, different sources are available at ITM (for example *Trypanozoon* databank, Nucleic acid Trypanozoon databank and clinical samples databank). The WHO Biobank on HAT patients and controls is also available.

Still, to date, no commercial assay is available for molecular diagnostics for *T. b. gambiense*, and all assays are based on in-house standard operating procedures (SOPs). Furthermore, no common standard exists on sampling, extraction or amplification. TgsGP remains the main target to confirm *T. b. gambiense* type I, but different formats for detection exists, with variable validation, and no clear sensitivity and specificity data exist. As efforts are made to develop new molecular methods

that specifically detect *T. b. gambiense*, validation of specificity is crucial, for which a very good collection of trypanosomes samples is needed.

DETECTION OF *T. B. GAMBIENSE* INFECTIONS IN TSETSE FLIES (XENOMONITORING)

In the context of gHAT surveillance and elimination, xenomonitoring is the collection and screening of tsetse flies to test for the possible presence of human-infective trypanosomes. The process can be broken down into three steps: the trapping of the target vector, the processing of the vector, and the interpretation of the results.

An example of xenomonitoring in the context of gHAT elimination is provided by a study undertaken in North-western Uganda (Cunningham *et al.*, 2020). For this study, tsetse were trapped between 2013 and 2014 in the district of Koboko, where very few cases of gHAT had been reported in the previous years and where no vector control was taking place. A total of 12 152 flies were caught, 6 664 were dissected and 2 184 underwent PCR reactions at the species and sub-species level. A positive rate of 1.8 percent was found for *T. brucei* s.l., while no *T. b. gambiense* was detected.

In general, tsetse trapping is a relatively straightforward task, and it can be used simultaneously for xenomonitoring and for vector monitoring. However, catching a sufficient number of flies for xenomonitoring is more complex. This is because gHAT infection rates in tsetse are generally very low, even in the more active transmission foci. Because of the high number of flies needed, it is also unlikely that xenomonitoring could be associated to vector control, as the latter reduces tsetse densities. Also, to be informative in the context of gHAT elimination, trapping may need to be carried out over wide geographical areas and for a prolonged period, and an ability to pool samples while maintaining sensitivity is also likely to be needed.

As regards the processing of flies, the very low sensitivity of the available tools is arguably the most serious challenge. In particular, the molecular method presently in use to detect *T. b. gambiense* in tsetse relies on a single copy gene (Radwanska *et al.*, 2002). In comparison, the PCR used for the detection of T. brucei s.l. exploits a 15k copy gene (Deborggraeve and Büscher, 2012). The need for a laboratory setting is another issue of existing methods, while it would be useful to perform the tests close to the trapping, in both space and time. To tackle these and other issues, new tools are presently under development that could improve the detection of *T. b. gambiense* in tsetse flies.

An additional issue in tsetse processing and in the interpretation of the results is the fact that not all positive flies are infected. In fact, a positive molecular test could indicate a past encounter with the parasite rather than an active infection. More in general, correctly interpreting the results from xenomonitoring is expected to be very challenging, especially if they are to be used to inform actions. Also, the cost of monitoring in near elimination settings will need to be weighed against the long-term cost of a failure to determine if elimination has been achieved. There is no doubt that proving with certainty the absence of gHAT will be difficult, so care will be needed in the definition of the elimination criteria to avoid prematurely declaring the absence of disease. As regards xenomonitoring, it is apparent that new, more efficient technologies are needed to both sample and screen tsetse if the technique is to make a meaningful contribution to the process of verification of gHAT elimination.

Despite all the challenges in xenomonitoring, also active and passive medical surveillance have limitations in an elimination setting, and some of these limitations could be offset by the strengths of xenomonitoring. For example, the possible presence of an animal reservoir and of silent human carriers calls for complementary, pragmatic environmental sampling methods. Also, xenomonitoring could contribute to AAT surveillance, thus enhancing its viability in the context of gHAT elimination. Finally, xenomonitoring for gHAT need not be limited to tsetse; indeed, other hematophagous insects could be used to increase sample size and, in the process, promote integration in NTDs surveillance and reduce costs (Cook *et al.*, 2017).

Molecular biology and tsetse control

Molecular biology can contribute to tsetse control by improving the efficacy of existing control tools (for example traps and targets), developing new tools and assisting the implementation of operations on the ground (for example SIT). It can also be used in an attempt to reduce vector competence by blocking trypanosome infection or transmission.

Research in this area received a major boost in 2004, when the International *Glossina* Genome Initiative (IGGI) was launched under the auspices of WHO Special Programme for Research and Training in Tropical Diseases (TDR). One of its major achievements was the publication of the first *Glossina* genome for *G. morsitans morsitans* (International *Glossina* Genome Initiative *et al.*, 2014), and then for five additional species (Attardo *et al.*, 2019). Microbiota genomes were also discovered for various tsetse species, and genomics and RNA data were generated for multiple trypanosome species and strains.

Areas of molecular biology with innovation potential for tsetse control include (i) bottlenecks in tsetse physiology to reduce fecundity; (ii) parasite-resistant lines (that is, paratransgenic flies) to enhance SIT; (iii) olfaction to improve traps, targets or repellants; and (iv) population genetics to target vector control (Chahda *et al.*, 2019; Soni, Chahda and Carlson, 2019; Wachira *et al.*, 2020; Wachira *et al.*, 2021). The development of metacyclic vaccines is another area with potential for the development of new tools (Vigneron *et al.*, 2020).

Further research in these areas would expand the available toolbox against tsetse, and it should be accompanied by transfer of capacity to African laboratories. Reinforced links between the research community, national authorities and policy makers would also enhance the transfer and application of successful technologies for long-term, sustainable control of trypanosomosis in a One-Health framework.

Conclusions

1. Vector control contributes to curbing the transmission of gHAT by reducing tsetse densities and tsetse-human contact; it is therefore a valuable addition to medical interventions to support the elimination of the disease.
2. In the past few years, progress in bait technologies, and in particular in small-size insecticide-treated targets ("tiny targets"), provided novel, more affordable tools to implement vector control in gHAT endemic areas. A broader array of vector control tools exists which can be used either as a stand alone or in an integrated manner, depending on the local epidemiological conditions. These include insecticide-treated targets, insecticide-treated cattle, livestock protective fences, insecticide ground spraying and aerial spraying and the sterile insect technique.
3. There is a need to enhance and harmonize metrics to estimate the coverage of vector control in space and time, with a view to improving reporting and monitoring of vector control interventions at the national and continental level.
4. Ongoing efforts aimed at improving tsetse mapping (for example FAO continental atlas and country-owned national atlases) should be sustained, and synergies with the WHO atlas of HAT should be explored.
5. There is a need to better develop criteria and approaches to prioritize areas for vector control interventions with a view to targeting vector control in areas where its impact can be expected to be highest.
6. Better integration of interventions against gHAT and African animal trypanosomosis (AAT) in a One-Health framework is needed; this holds the potential for enhanced impacts of vector control at the human-animal-environment interface, broader partnerships and widened resource base.
7. The challenges of sustainability of vector control and of sustained community engagement must be addressed against a backdrop of diminishing gHAT cases. Innovative approaches to vector control (for example reactive vector control and One-Health vector control interventions) should be explored for adapted and cost-effective solutions.
8. There is room for existing vector control tools and approaches to be improved, including the development of less polluting devices and the promotion of safe disposal after use.
9. There is a need to strengthen coordination of vector control activities implemented by different partners in gHAT endemic areas. The present meeting and a forum such as PAAT offer a suitable platform to enhance exchange of information and coordination.
10. Additional efforts must be devoted to increasing country ownership of vector control activities and progressively diminishing reliance on external partners.
11. Tools to detect *T. b. gambiense* infections in tsetse flies and in other blood feeding insects need to be improved, with a view to contributing to the verification of the elimination of gHAT transmission.
12. The organization of a meeting of vector control experts in the framework of the WHO network for HAT elimination should be considered on a periodic basis (e.g. annually).

Annex 1

Agenda of the meeting

DAY 1	5 OCTOBER 2021, 14.00-17.30 (CET)	
TOPICS	SITUATIONAL UPDATE: VECTOR CONTROL AND GHAT ELIMINATION IN ENDEMIC COUNTRIES	
	Opening	
14.00 – 14.05	Opening remarks FAO	**Keith Sumption** Chief Veterinary Officer/Leader Animal Health Programme Animal Production and Health Division (a.i.), Director of Joint FAO/WHO Centre
14.05 – 14.10	Opening remarks WHO	**Daniel Argaw Dagne** Coordinator of the 'Prevention, Treatment and Care' unit NTD/WHO
14.10 – 14.15	Opening remarks PAAT	**Weining Zhao** Senior Animal Health Officer Focal Point of PAAT Secretariat FAO
14.15 – 14.25	Introduction of attendees	**José Ramon Franco** NTD/WHO
14.25 – 14.35	Meeting programme and objectives	**Gerardo Priotto** NTD/WHO
14.35 – 14.40	***Group photo***	
	Background and overview	
14.40 – 14.55	Gambiense HAT elimination: background, progress status and prospects. Role of vector control in the gHAT elimination	**José Ramon Franco** NTD/WHO
14.55 – 15.15	Vector control and gHAT: an overview	**Rajinder Saini** Member of WHO - Expert Advisory Panel on Parasitic Diseases (Trypanosomiasis)
	Recent and ongoing field activities in endemic countries	
15.15 – 15.25	Vector control and gHAT elimination in Guinea	**Mamadou Camara and Moïse Sâa Kagbadouno** *Programme national de lutte contre la Trypanosomiase humaine africaine (PNLTHA) - République de Guinée*
15.25 – 15.35	Vector control and gHAT elimination in Côte d'Ivoire	**Lingue Kouakou** *Programme national d'élimination de la Trypanosomiase humaine africaine (PNETHA) - Côte d'Ivoire*
15.35 – 15.45	Vector control and gHAT elimination in Cameroon	**Alphonse Acho** PNLTHA Cameroun
15.45 – 15.55	Vector control and gHAT elimination in Chad	**Jean Claude Peka Mallaye and Brahim Guihini** PNLTHA Tchad
15.55 – 16.05	Vector control and gHAT elimination in the Democratic Republic of the Congo	**Erick Mwamba Miaka** PNLTHA République Démocratique du Congo (RDC)
16.05 – 16.15	Vector control and gHAT elimination in Uganda	**Charles Wamboga** Vector Control Division - Uganda
16.15 – 16.25	Vector control and gHAT elimination in Angola	**Constantina Pereira Furtado Machado and Don Paul Makana** *Instituto de Combate e Controlo das Tripanossomíases (ICCT) - Angola*
16.25 – 16.40	The Pan-African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) and the elimination of gHAT	**Gift Wanda** African Union – PATTEC
16.40 – 17.30	***Open discussion***	

DAY 2	6 OCTOBER 2021 (09.00 – 12.00 AND 14.00 – 17.00 CET)	
TOPICS	TOOLS, METHODOLOGIES, APPROACHES, SCIENTIFIC ASPECTS AND CROSS-CUTTING THEMES (ONE-HEALTH, ECONOMICS, REPORTING METRICS AND ESTIMATION OF THE IMPACTS)	
	Tools and approaches: State-of-the-art (production, conditions and locations of use, intensity & coverage, community participation, sustainability)	
9.00 – 09.30	Bait and insecticide technologies to control tsetse, with a focus on 'tiny targets': advances and prospects	**Iñaki Tirados** Liverpool School of Tropical Medicine (LSTM) - UK
9.30 – 09.45	Area-wide integrated management of tsetse with a SIT component	**Chantel de Beer** International Atomic Energy Agency (IAEA)
9.45 – 10.00	Livestock Protective Fences	**Burkhard Bauer** Independent Scientific Advisor Institute for Parasitology and Tropical Veterinary Medicine - Free University of Berlin - Germany
10.00 – 10.30	Open discussion	
	Economics: costs and feasibility	
10.30 – 10.45	The cost of vector control in the context of gHAT elimination, with a focus on 'tiny targets'	**Alexandra Shaw** AP Consultants - UK
10.45 – 11.00	Feasibility of community-based control of tsetse in the Democratic Republic of the Congo	**Catiane Vander Kelen** *Institute of Tropical Medicine Antwerp (ITM) - Belgium*
11.00 – 11.15	Vector control and gHAT elimination: a One-Health perspective	**Philippe Solano** *Institut de recherche pour le développement (IRD) - France*
11.15 – 12.00	Open discussion	
12.00 – 14.00	***Lunch break***	
	Reporting metrics and estimation of the impacts	
	Estimating the geographic and temporal coverage of vector control and its impacts on tsetse densities: options and perspectives.	
14.00 – 14.10	Indicators to monitor the elimination of human African trypanosomiasis	**Giuliano Cecchi** FAO
14.10 – 14.25	Possible indicators on vector control: options and perspectives	**Iñaki Tirados** LSTM - UK
	Process of verification of gHAT elimination and possible role of entomological indicators	
14.25 – 14.35	Background on the process of verification of gHAT elimination	**Veerle Lejon** IRD Chairperson of the WHO HAT elimination Technical Advisory Group (HAT-e-TAG)
14.35– 14.50	Detection of *T. b. gambiense* infections with molecular tools	**Nick Van Reet** ITM - Belgium
14.50 – 15.05	Detection of *T. b. gambiense* infections in tsetse flies (xenomonitoring)	**Lucas Cunningham** LSTM - UK
15.05 – 15.20	Molecular biology and tsetse control	**Serap Aksoy** Yale School of Public Health - USA
15.20 – 16.00	Open discussion	
16.00 – 16.30	Recommendations, gaps and research needs	
16.30	***Official closing***	

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Human African trypanosomiasis (HAT) is a vector-borne parasitic disease transmitted by tsetse flies in sub-Saharan Africa. The gambiense form of the disease (gHAT) is endemic in western and central Africa and is responsible for more than 95 percent of the HAT cases reported annually. In the road map for neglected tropical diseases 2021–2030, WHO targeted gHAT for elimination of transmission by 2030. FAO supports this goal within the framework of the Programme against African Trypanosomosis (PAAT).

In the framework of the WHO network for HAT elimination, FAO and WHO convened a virtual expert meeting to review vector control in the context of gHAT elimination. The experts included health officials from endemic countries and representatives from research and academic institutions, international organizations and the private sector. Seven endemic countries provided reports on recent and ongoing vector control interventions against gHAT at national level (i.e. Angola, Cameroon, Côte d'Ivoire, Chad, Democratic Republic of the Congo, Guinea and Uganda). The country reports were followed by thematic sessions on various aspects of vector control: tools, costs, community-based approaches, monitoring and reporting. Tsetse control was also discussed in the broader framework of One Health, and in particular in relation to the control of animal trypanosomosis. This report presents a summary of the findings and lessons learned.

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