CABI

Action on Invasives Report 2020

KNOWLEDGE FOR LIFE

Contents

Acronyms 3

Introduction 4

Executive summary 7

Programme highlights 10

Stakeholder Engagement: Fostering the Right Partnerships 12

Providing Best Practice Solutions for Invasive Species 19

Community Action: Bringing Information and Action to Scale 27

Knowledge and Data: Creating and Using Information 31

Monitoring and evaluation 36

Publications 42

Annex 1: Associated projects 46

Annex 2: Conferences/workshop attendance 49

Annex 3: 2020 milestones 50

Acronyms

ASEAN	Association of Southeast Asian Nations
AU	African Union
BARI	Bangladesh Agricultural Research Institute
COLEACP	Comité de liaison Europe – Afrique – Caraïbe – Pacifique
CIMMYT	International Maize and Wheat Improvement Centre
DGIS	Netherlands Directorate-General for International Cooperation
DOI	Digital Object Identifier
DPP	Department of Plant Protection
EPN	Entomopathogenic nematode
FCDO	UK Foreign, Commonwealth and Development Office
GBCL	Global Burden of Crop Loss
GBIF	Global Biodiversity Information Facility
GRDC	Grains Research and Development Corporation
HLB	Huanglongbing
IAS	Invasive alien species
IITA	International Institute of Tropical Agriculture
IPM	Integrated pest management
IPPC	International Plant Protection Convention
ISC	Invasive Species Compendium
KALRO	Kenya Agricultural and Livestock Research Organization
KSTCIE	Kenya Standing Technical Committee on Imports and Exports
MARDI	Malaysian Agricultural Research and Development Institute
NISSAP	National Invasive Species Strategy and Action Plan
NPPO	National Plant Protection Organization
ODK	Open Data Kit
PPRSD	Plant Protection and Regulatory Services Directorate
PRA	Pest risk analysis
PRSP	Punjab Rural Support Programme
SAARC	South Asian Association for Regional Cooperation
SDG	Sustainable Development Goal
USDA	United States Department of Agriculture

Introduction

Action on Invasives is a programme led by CABI which is addressing the growing problem of invasive species in agriculture and the natural environment. This is not a new problem, but climate change, trade and tourism are all exacerbating the situation and increasing the urgency of achieving a co-ordinated and effective response at local, national and regional levels. Invasive species disproportionately affect vulnerable and rural communities, undermining sustainable development. The Sustainable Development Goals (SDGs) therefore include a goal to "introduce measures to prevent the introduction and significantly reduce the impact of invasive species on land and water ecosystems and control or eradicate the priority species" (SDG 15.8).

It is internationally agreed that the overall technical approach to managing invasive species comprises three tiers: prevention (stopping them invading in the first place); early detection and rapid response (eradication and/or containment); and – for species that become permanently established – control and mitigation of the impacts. All too often it is the third tier that gets most attention, despite the fact that prevention is widely recognized as being more cost-effective. Action on Invasives is designed to enable countries and regions to adopt this three-tiered approach through four interrelated work packages:

- Stakeholder Engagement – Fostering the Right Partnerships
- Best Practice Solutions – For Prevention, Control and Mitigation
- Community Action – Bringing Information and Action to Scale
- Knowledge and Data – Creating and Using Information

The lead donors to the programme are the UK's Foreign, Commonwealth and Development Office (FCDO) and the Netherlands' Directorate-General for International Cooperation (DGIS). A number of organizations have also contributed to the aims of the programme in 2020 through supporting the associated projects listed in Annex 1.

The COVID-19 pandemic had a major impact on the programme in 2020, with all countries in which the programme operates experiencing restrictions to varying degrees at different times. In line with CABI's policy, the safety and well-being of staff and partners was paramount, and all activities were undertaken within national regulations. Opportunities for meetings and workshops were limited, and no regional or international face-to-face meetings were possible, though local training courses and workshops were possible in some cases, with appropriate safety measures. Virtual meetings were extensively used. While not providing the same depth of interaction as physical meetings, and in some cases suffering from technical constraints, they provided the

Monthly highlights

FEBRUARY

Horizon scanning to prioritise invasive species risks completed in Ghana

APRIL

61,000 species distribution data points added to the Invasive Species Compendium

JUNE

Fall Armyworm Research Collaboration Portal launched

AUGUST

Videos on use of Green Muscle for desert locust control commissioned

SEPTEMBER

Pakistan receives first shipment of *Eiphosoma laphygmae*, a fall armyworm natural enemy

OCTOBER

Trial releases of *Telenomus remus* for fall armyworm control in Ghana

NOVEMBER

Farmer survey finds 40% reduction in pesticide use for fall armyworm control

DECEMBER

Apple snail *Pomacea canaliculata* confirmed present but not yet widespread in Kenya

opportunity to achieve more than might have been anticipated. Virtual webinars and conferences allow a larger number of participants at lower cost than physical meetings. Almost no international travel was undertaken, although some local travel was possible, where necessary with specific government approval. Thus some field and laboratory work continued.

In response to the restricted and frequently changing operating environment, planned activities and milestones for the year were adapted where necessary, as follows:

- planned activities only marginally affected, so little or no change
- planned activities modified, but with the same/similar budget
- planned activities reduced/modified, and the budget reduced
- planned activities expanded, with an increased budget
- new activities, including responding to emerging problems

The main focus of this report is on what was achieved during 2020. The milestone table (Annex 3) summarizes the adjustments that were made to the original plans.

Action on Invasives is working through selected countries, which are considered to be focal points, from where activities can then be regionalized. The first participating countries were Ghana, Kenya, Pakistan and Zambia, and in 2019 activities were initiated in Rwanda and Bangladesh. In 2020, some activities were initiated in Burkina Faso, but neither there nor in Rwanda and Bangladesh was it feasible to expand activities. Similarly, as entry points for addressing issues of invasive species in general, in 2020 the focus species continued to be fall armyworm (*Spodoptera frugiperda*), tomato pinworm (*Phthorimaea absoluta*, re-named from *Tuta absoluta* in 2020) and parthenium weed (*Parthenium hysterophorus*), with some activities on papaya mealybug (*Paracoccus marginatus*), mesquite (*Prosopis juliflora*), apple snail (*Pomacea canaliculata*) and desert locust (*Schistocerca gregaria*).

In 2021, Action on Invasives will merge into CABI's new global programme, PlantwisePlus, and this is therefore the last annual report for Action on Invasives as a separate programme. Major elements of Action on Invasives will become part of PlantwisePlus, and so in the future the continuing activities described here will be reported under the new programme.

Executive summary

Work was planned for 2020 in Bangladesh, Burkina Faso, Ghana, Kenya, Pakistan, Rwanda and Zambia, but all those countries, as well as others where CABI offices are located, experienced restrictions during the year, due to the COVID-19 pandemic. However, operating within national regulations and CABI's policies, significant achievements were made by modifying ways of working and adapting activities. Of the 33 milestones for the year, 10 required little or no change in plans, and 10 were adjusted within the budget allocated. Activities and budgets in a further 10 milestones were cut back, but for three milestones, activities were expanded. While aiming to strengthen the capacity of invasive species management in general, the main focus species for the programme in 2020 continued to be fall armyworm (*Spodoptera frugiperda*), tomato pinworm (*Phthorimaea absoluta*, formerly called *Tuta absoluta*) and parthenium weed (*Parthenium hysterophorus*). Some activities were also undertaken on papaya mealybug (*Paracoccus marginatus*), mesquite (*Prosopis juliflora*), apple snail (*Pomacea canaliculata*) and desert locust (*Schistocerca gregaria*).

In the **Stakeholder Engagement** work package, the programme facilitated linkages between stakeholders to develop and implement evidence-based plans, regulations, and practices for responding to invasive species. National invasive species system assessments were conducted in Bangladesh and Zambia, and cross-sectoral working mechanisms for addressing invasive species were established and operationalized in Kenya and Ghana. A national invasive species strategy and action plan (NISSAP) was drafted in Pakistan, and in four countries opportunities were identified for linking climate change adaptation plans to invasive species management.

Support was provided to the development and implementation of regulatory procedures that facilitate the use of lower-risk control products, including guidelines for the import and release of biological control agents in Ghana. A lower-risk biopesticide for desert locust was promoted through a set of animated videos and a strategy paper. Trials conducted previously with manufacturers of a virus product and a pheromone product for fall armyworm resulted in the products receiving registration in Kenya.

Countries were supported to develop and implement plans for responding to desert locust and apple snail, two species that became high priorities in 2020.

The evidence base for the cost of invasive species, particularly in lower-income countries, is still weak but an assessment of the costs for selected species that are already widespread in Africa was completed, and with the Global Burden of Crop Loss initiative (GBCL) methods were developed for estimating global losses by country. The potential cost to the East African citrus industry of the newly invaded Asian huanglongbing (HLB) disease was estimated.

The **Best Practice Solutions** work package continued to develop methods for the cost-effective prevention, early detection and control of invasive species. Horizon scanning and prioritization of potentially invasive plant pests was completed in Ghana and initiated in Pakistan, and surveillance was undertaken in Ghana and Kenya for prioritized species.

In Pakistan, host specificity testing of *Listronotus setosipennis* for classical biological control of parthenium was completed, on the basis of which an application to release the species was prepared. Work continued to understand and manipulate the impact of two other biological control agents that have been found in Pakistan, *Zygogramma* beetle and winter rust disease, though neither is effective in all areas where parthenium is found.

Research to develop biological control of fall armyworm in Africa and Asia progressed well. Significant egg and larval mortality occurs due to natural enemies already present, but this is affected by pesticide use, cropping systems and agronomic practices. The first trials of augmentative biological control with egg and larval parasitoids of fall armyworm were conducted in Ghana and Bangladesh, but a cost-effective solution cannot be recommended yet. *Eiphosoma laphygmae*, a parasitoid of fall armyworm from the Americas, was found to be host-specific in laboratory trials, and so has good potential as a classical biological control agent. Shipments were made to Pakistan and Benin, where cultures are being established for further tests prior to application for field release. Several biopesticides are now known to be effective for fall armyworm control, but registration of these products is patchy, and they are still not available in many countries. Field trials with entomopathogenic nematodes have shown they can effectively control fall armyworm, but a cost-effective production and distribution system is needed.

During 2020, work continued on biological control and integrated pest management (IPM) of other priority species. A parasitoid of papaya mealybug, *Acerophagus papayae*, was imported from Ghana to Kenya for tests in quarantine, prior to an application to release it as a classical biological control agent. Several components of IPM of tomato pinworm were assessed for their cost-effectiveness, and a number of natural enemies were discovered, providing opportunities for augmentation.

The **Community Action** work package sought to understand and address what helps or hinders communities in adopting recommended practices for managing invasive species. A gendered technology assessment of fall armyworm biopesticides highlighted the benefits of non-chemical control methods to women, particularly those methods that do not require labour for spray application. The products are not always available and affordable, though in Ghana, where the government has promoted the use of biorational pesticides, biopesticides are the most widely used products. Also in Ghana, a household study was conducted in 2020 which found that over the last 2 years, farmers have adopted more agronomic practices and the average number of pesticide applications per season has fallen from 2.5 to 1.5. But many farmers, particularly women, do not use sufficient personal protective equipment when applying pesticides. Perceived efficacy and price are key considerations in choice of control product. A further study was conducted in Ghana in 2020, on the overall way in which the armyworm problem has been addressed found that although the initial response was thought to be slow, once the coordination and oversight mechanism had been established, good communication and stakeholder collaboration led to positive outcomes.

During the year, communication campaigns to promote effective management of fall armyworm, parthenium, tomato pinworm and papaya mealybug were conducted in Pakistan, Ghana, Kenya, Zambia and Bangladesh, reaching nearly 1 million people. The use of remote communication methods (such as SMS and mass media) avoided restrictions due to the pandemic, but in Pakistan, an external evaluation commissioned by the programme in 2020, of the parthenium campaign conducted in 2019, found that face-to-face meetings were also cost-effective. In Pakistan collaboration with rural development organizations enabled face-to-face extension to continue.

IPM of tomato pinworm was tested with over 1,000 farmers in Kenya, and the cost-effectiveness was demonstrated. The benefits reported include reduced use of pesticides, which farmers know can cause health problems. A partnership with a company producing baculoviruses for control of fall armyworm and tomato pinworm in Ghana was established, to investigate possibilities for the local multiplication of virus products by farmers and communities.

During the year, the **Knowledge and Data** work package added new tools and enhanced existing ones to improve the accessibility and use of information for the prevention and management of invasive species. The Pest Risk Analysis (PRA) tool was upgraded to make it easier to use by individuals and teams working on a risk analysis. Furthermore, recognizing that there are still many national plant protection organization (NPPO) staff who are not fully conversant with undertaking a PRA, additional help was incorporated in the tool. Collaboration was established with Comité de liaison Europe – Afrique – Caraïbe – Pacifique (COLEACP) and the International Plant Protection Convention (IPPC) Secretariat to develop PRA e-learning materials to further address this need. A fall armyworm research collaboration portal was developed and launched, with the aim of promoting information exchange and collaboration among researchers. The portal is well used, but the unwillingness of researchers to share unpublished information detracts from its potential.

The Invasive Species Compendium (ISC) continued to grow in popularity, with visits reaching a record 3.4 million in 2020. Various enhancements were made to improve the visual presentation of distribution data on maps, and to speed navigation to the required information, particularly when using a mobile device. Datasheets were created for additional species, and a new species portal was added for apple snail, following its discovery in Kenya. The distribution database that underpins the ISC, the Horizon Scanning Tool and the PRA tool, was upgraded, facilitating bulk uploading of datasets and resulting in updated information for around 2,500 species. An evaluation of the ISC has shown that it is particularly valued by users because it is up-to-date, reliable and open access. It is used for a variety of purposes, including research, identifying invasive species, risk assessment and prioritizing species for action, developing management plans, and creating materials for public awareness and extension.

From 2021, Action on Invasives will no longer operate as an independent programme. Its objectives have been merged into CABI's new global programme, PlantwisePlus, so many of the ongoing activities reported here will continue and will be reported under the new programme.

Programme highlights

Stakeholder Engagement

- The highly invasive snail, *Pomacea canaliculata,* was discovered in Kenya – the first report in mainland Africa. A delimiting survey was carried out, which showed that it is not yet widespread.
- A national desert locust strategy for Kenya was developed.
- Videos and an evidence note were produced on the use of Green Muscle™ for desert locust control.
- A national invasive species strategy was drafted for Pakistan.
- National technical working groups on invasive species were established in Ghana and Kenya.
- Opportunities were identified for linking climate change adaptation plans to invasive species management.
- An assessment was carried out of the costs of invasives in Africa; this showed that labour for management is a major cost.
- The potential economic impacts of citrus HLB in East Africa were assessed.
- Guidelines for the import and release of biological control agents in Ghana were drafted and adopted.
- A policy enquiry was conducted on the implementation of a fall armyworm management plan in Ghana.
- National invasive species system assessments were conducted in Bangladesh and Zambia.

Best Practice Solutions

- Horizon scanning and prioritization of potentially invasive plant pests was completed in Ghana and initiated in Pakistan.
- Surveillance programmes were carried out in Ghana and Kenya to assess the presence of priority invasive pest species and strains.

- Host range testing was completed for *Listronotus setosipennis*, a biological control agent for parthenium weed; an application for field release of the agent was drafted for Pakistan.
- Over 20 parasitoid species cause high mortality to fall armyworm in Africa and Asia. In this context, increasing the impact of natural enemies through cultural practices was tested.
- The first trials of augmentative biological control with egg and larval parasitoids of fall armyworm were conducted in Ghana and Bangladesh.
- The fall armyworm parasitoid *Eiphosoma laphygmae* was found to be host-specific, and was shipped to Pakistan and Benin for further tests prior to field release.
- Several biopesticides were shown to be effective for fall armyworm control. A review of biopesticides for fall armyworm in Africa was updated.
- Collaborations with Rwanda showed that entomopathogenic nematodes can control fall armyworm, but not yet cost-effectively.
- The papaya mealybug parasitoid, *Acerophagus papayae*, was imported from Ghana to Kenya for tests in quarantine prior to release.
- A technical and economic evaluation of components of tomato pinworm IPM was carried out.

Community Action

- A gendered technology assessment of fall armyworm biopesticides highlighted the benefits of non-chemical control methods.
- A household study in Ghana showed that farmers have adopted more agronomic practices and reduced synthetic pesticide use for fall armyworm control since 2018, in line with recommendations.
- Over 1,000 farmers in Kenya trialled and evaluated IPM of tomato pinworm, reporting various benefits from reduced use of pesticides.
- Communication campaigns in Pakistan, Ghana, Kenya, Zambia and Bangladesh reached over 900,000 people.
- Evaluations of a parthenium communication campaign in Pakistan and a fall armyworm SMS campaign in Zambia were completed.
- Collaborations took place with the private sector to trial community multiplication of baculoviruses for fall armyworm in Kenya and tomato pinworm in Ghana.

Knowledge and Data

- Major enhancements to the PRA tool increased usability for individuals and teams working online and offline.
- The Fall Armyworm Research Collaboration Portal was launched, and over 600 users have registered.
- There were over 3.4 million visitors to the ISC in 2020, up 66% on 2019.
- An evaluation of the ISC confirmed its value for lower- and middle-income countries as an up-to-date, reliable and open access information source for multiple uses.
- Improvements were made to the ISC's functionality for mapping data and rapidly accessing required information.
- A new ISC species portal on apple snail *P. canaliculata* was launched.
- CABI's pest distribution database was improved to accelerate bulk data updates, directly benefiting the ISC, the Horizon Scanning Tool and the PRA tool.

Stakeholder Engagement: Fostering the Right Partnerships

National, regional and international stakeholders in the public and private sector need to work together to achieve sustainable management of invasive species. Action on Invasives is building on and extending the linkages established through Plantwise and other programmes. Through such partnerships, evidence-based policy, plans and practices can be developed and implemented.

Progress in 2020

National response plans for managing priority invasives

Following reports of an invasive snail causing crop damage in the expansive Mwea irrigation scheme in Kenya, the programme assisted with some of the key steps taken to respond to this new invasion. DNA barcoding at CABI's UK laboratory revealed the snails to be the apple snail, *Pomacea canaliculata*, a major invasive invertebrate present in waterways and irrigation in Asia. A delimiting survey was conducted in the three rice-growing irrigation schemes in Kenya to establish the spread of apple snail in the country, in order to inform possible containment actions to limit the spread to other areas at risk. The survey showed that over 80% of the Mwea scheme's sections were infested, but no adults or eggs were detected in other rice schemes which are at high risk due to the frequent transfer of planting materials and farm machinery from Mwea. Measures to contain further spread in Kenya are being planned. As this is the first confirmed report of *P. canaliculata* in continental Africa (it is present in La Réunion and Mauritius), and given the significant impact of the species in Asia, there is a need for an assessment of the risk to Africa, and the implementation of an appropriate response in Kenya and elsewhere to manage this new threat to agriculture and the environment. To support this preparedness an evidence note was drafted, and information was collated and made available through the new apple snail portal in the ISC.

The desert locust invasion in Kenya had highlighted the absence of any response strategy, so the programme worked with the Ministry of Agriculture, Livestock, Fisheries and Cooperatives to develop a comprehensive national desert locust management strategy. All major stakeholders made inputs to the strategy, which articulates objectives for technology, capacity, research, surveillance and early warning, IPM, communication, policy and co-ordination. The strategy defines the roles and responsibilities of actors in county and national governments, research institutions, regulatory agencies, the general public, as well as regional and international organizations.

Responding to a new invasion

The invasive apple snail *Pomacaea canaliculata* has been discovered in Kenya, the first confirmed report from mainland Africa. Action on Invasives has supported the national response, helping address critical questions.

1 What species is it?

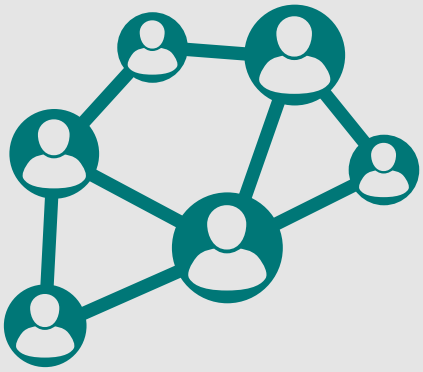
DNA barcoding showed the species to be *P. canaliculata*, and not the related *P. maculata* or a hybrid of the two.

What are the risks? 2

An information portal (www.cabi.org/isc/gas) has been set up, and an evidence note written, to provide the information Kenya and other countries need to assess and manage the risks.

3 How far has it spread?

A delimiting survey showed the snail is present only in one rice scheme. So there's still opportunity to stop it spreading further.



What to do next? 4

A national task force, including CABI, has been set up to coordinate the response.

In 2019, Action on Invasives had supported the initial drafting of a national strategy for managing the highly invasive *Prosopis juliflora* in Kenya. In 2020, following wider stakeholder consultations, technical assistance was provided to complete the strategy. The strategy provides for co-ordinated action by local, national and international stakeholders in government, the private sector and civil society. CABI is a member of the National Technical Implementation Committee for the strategy, which has a set of well-defined tasks. The strategy is awaiting gazettement and official launching by the Cabinet Secretary.

National and regional strategies for managing invasive species

In Pakistan, a national invasive alien species (IAS) strategy was developed, outlining short-, medium- and long-term objectives. Areas covered include prevention, early detection and response, control, restoration, research and information management, education, awareness and capacity building, and international cooperation. The first result area under the IAS strategy is co-ordination and liaison, which includes establishing a cross-sectoral Technical Review Committee to supervise the implementation and monitoring of the strategy, including prioritizing species for prevention and/or control.

Following the system assessment in Kenya during 2019, and the development of a NISSAP in Ghana, in 2020 both countries established a national technical working group on invasive species. In Ghana the working group is reviewing the results of the horizon scanning undertaken in 2020, to agree activities and contingency plans for prevention, early detection and rapid response for the identified high risks.

Desk studies were undertaken in Pakistan, Zambia, Kenya and Ghana, examining the potential for interlinkages across national planning processes for climate change adaptation, invasive species and biodiversity. While there is some coverage of invasives in national climate plans and policies, they receive little attention, except within the broader area of biodiversity. The greatest area of interlinkages (except in Ghana) is in natural resource management, particularly integrated ecosystem-based adaptation and community-based adaptation approaches. There are opportunities for more co-ordinated efforts at the 'meso' level for natural resource governance and planning which could address both invasives and climate adaptation simultaneously with the same stakeholders. This would link well to the recently-launched principles of locally-led adaptation, and the renewed focus on nature-based solutions which will be prioritized at the 2021 United Nations Climate Change Conference. The greatest area of potential for technical interlinkages lies in the development and promotion of early warning systems. In national policies these are primarily focused on weather-related extreme events (flooding, drought, cyclones and landslides), but there is scope to extend this to pest and disease outbreaks, and to address the root causes of climate vulnerability, which exacerbate risks, such as invasive plants depleting water availability and destabilizing soils.

Providing evidence of invasive species impacts to inform decision-making

During the year, a study to estimate the cost of IAS in Africa was completed, focusing on agriculture, the most important economic sector for the continent. Data on the monetary costs of IAS to mainland Africa, as well as information about the presence and abundance of the most important IAS, were collected through a literature review and an online survey conducted with a variety of experts. The data were used to calculate yield losses and management costs for individual countries and the continent, and for selected invasive species and crops. Even for well-known species, there was found to be a paucity of reliable data. For individual crop pests and diseases, the annual value of yield loss in Africa was estimated as follows: fall armyworm (*Spodoptera frugiperda*) $9.2bn; larger grain borer (*Prostephanus truncatus*) $0.37bn; spotted stem borer (*Chilo partellus*) $2.59bn; cassava mealybug (*Phenacoccus manihoti*) $6.25bn; tomato pinworm (*Phthorimaea absoluta*) $4.15bn; banana bunchy top virus $0.57bn; oriental fruit fly (*Bactrocera dorsalis*) $5.82bn. For weeds there was found to be inadequate data on yield loss, but the total days spent weeding invasives per hectare per year in major crops was calculated as follows: cereals (excluding maize) 50.0 days; legumes 54.2 days; maize 54.6 days; root crops 92.0 days; vegetables 82.7 days. Putting a cost on family labour is difficult, but using the minimum daily wage, the total annual cost of this labour would amount to $3.63tn per year. Invasives also cause major costs to other sectors (such as forestry, fisheries, infrastructure and trade), but these were not assessed due to a lack of data. The study was submitted for publication.

Action on Invasives is also working closely with and supporting the GBCL, which was initially funded by the Bill and Melinda Gates Foundation, and aims to measure global trends in crop loss and the impacts of crop pests and diseases, so that the allocation of resources and prioritization of efforts can be matched to need. A five-year roadmap is being developed, and a consultancy has been commissioned to design scalable governance structures to support the growth of the initiative. Further interviews with potential users of the initiative's outputs in the public and private sector were conducted during 2020, confirming demand for economic metrics that are produced with scientific independence and rigour. A technical assessment of data platform requirements was conducted, as well as an assessment of how CABI's databases can be a part of that. A first loss assessment for maize will soon be undertaken, and data have been extracted from CABI's databases for 896 pests of maize. Related to the first GBCL iteration on maize, in 2020 Action on Invasives collaborated with the University of Minnesota to conduct a multi-peril risk and loss analysis of 12 important pests of maize, including fall armyworm. The results of the study will inform the GBCL methodology, as while a lot of loss data are reported on a species basis, the combined losses from all pests cannot simply be the arithmetic sum of the losses for each species. Preliminary results indicate that of the 15 countries with the largest maize-growing areas, Brazil and Argentina are among those with the highest risk exposure to the 12 pests investigated. Globally, areas that have more than nine of the assessed threats are mainly tropical, including most of sub-Saharan Africa, tropical South America, and South-East Asia. Fall armyworm has the highest predicted prevalence of all the species assessed.

Potential losses to Asian HLB disease of citrus were estimated for East Africa. While the African form of the disease, transmitted by the African citrus psyllid (*Trioza erytreae*), has been a problem for many years, the more damaging Asian form was first reported from orchards on the coast of Kenya in 2020. The vector for Asian HLB, the Asian citrus psyllid (*Diaphorina citri*), had already appeared in Tanzania in 2015 and Kenya in 2016, so there is now a risk that both the vector and the disease could spread widely in the region. The loss assessment study showed that if Asian HLB becomes widely established in East Africa, producers in hotter, lowland areas, which have previously been spared losses due to the less heat-tolerant African HLB, could face major losses due to the more damaging and heat-tolerant Asian HLB. The majority of citrus in the region is now at risk from one or both forms of HLB. The estimated annual value of lost production in four East African countries (Ethiopia, Kenya, Tanzania and Uganda) ranges from $21.3m to $63.8m within the next five to 10 years, with the potential to reach double that in the longer term. Economic losses could be greater still for major sub-Saharan African citrus producers, such as Nigeria and South Africa, if HLB spreads beyond East Africa, underlining the need for citrus-producing countries to assess and manage the risks, as well as to develop contingency plans. The analysis and recommendations from the study will be published in 2021.

Promoting registration of biological-based solutions

To facilitate the registration and use of biological-based solutions in Ghana, guidelines were developed and formally adopted covering the import and release of biological control agents and other beneficial organisms. The guidelines support implementation of the IPPC's international standard, and describe the responsibilities of the NPPO and other responsible authorities, importers and exporters. This is the first time the country has adopted guidelines for this class of biological agents, which will enable organizations to import and/or release these organisms following clear procedures. Following the international standard, the guidelines also cover the export of biological control agents.

In Pakistan, a consultative workshop was held for private and public sector organizations to review the context and implications of expected new regulations on biopesticide registration (especially for fall armyworm) being developed through a related CABI project (see Annex 1). Issues raised included the current absence of a clear regulatory framework for biopesticides, and the need for waivers and provisional registration to be considered in the revisions currently being undertaken. The workshop identified potential challenges in the upcoming regulations, including combinations of biopesticides and synthetic pesticides in the same product, and third-party testing of products and quality assessment by regulators. The workshop prioritized eight biopesticides

for fall armyworm, including nuclear polyhedrosis viruses (NPVs), fungal isolates of *Metarhizium* and *Beauveria*, and entomopathogenic nematodes (EPNs). Currently, none of these biopesticides are registered in the country. A desk review of biopesticide regulations was also conducted in Bangladesh. Microbial pesticides are covered under the Pest Control Products Act, which provides for biopesticide registration procedures similar to those used for chemical pesticides. Although this could be an impediment to microbial pesticide registration, the relatively rapid registration of Fawligen, the nucleopolyhedrovirus specific to the fall armyworm, suggests that this could be a case study of how biopesticide registration can work effectively within existing pesticide regulatory regimes in Bangladesh or other countries.

In the 1990s, CABI led an international consortium (LUBILOSA) that developed a low-risk biopesticide (Green Muscle™, *Metarhizium acridum*) for control of desert locust (*Schistocerca gregaria*). However, even in the current locust upsurge, Green Muscle™ has not been widely used, for a range of reasons, including lack of awareness of the product and it not being registered in all countries where it could be used. To address this, in liaison with the FAO, Action on Invasives developed five short animated videos promoting the use of the product, and covering application, dosage, storage and safe handling. The videos are targeted at regional and national policy-makers and decision-makers, as well as coordinators and advisors within agencies overseeing the desert locust emergency response. The videos can be used to support training on the use of Green Muscle™ by field operators. They are narrated in English, French, Russian and Arabic, and will be disseminated widely via social media channels and through CABI's networks. An evidence note on the use of Green Muscle™ was also produced, again targeting regional and national policy-makers and decision-makers and those managing the desert locust emergency response. The evidence note includes recommendations for how the supply of the product could be improved, so that it is more readily available when it is needed.

Action on Invasives had previously supported the development of the East African Community's harmonized guidelines for the registration of biopesticides and biocontrol products. Plans to support implementation of the guidelines were not possible, but in 2020 the guidelines were printed and distributed.

Building consensus on invasive species responses

The methodology developed for assessing national capacity to respond to invasive species was adapted and used in Bangladesh and Zambia, and is reported later (in the section on monitoring and evaluation). Regionally and internationally, contributions continue to be made where possible to support collaboration and co-ordination of initiatives against invasive species. Under FAO's 2020–2022 Global Action for Fall Armyworm Control, CABI leads the technical working group on communication and farmer awareness, and co-leads the group on biological control, sitting on the Technical Committee. Outcome 3 of the Global Action, concerning preparedness and reducing the risk of further spread, is led by the IPPC Secretariat, and CABI is a member of the IPPC working group co-ordinating the activities.

In Asia, CABI strengthened links with the South Asian Association for Regional Cooperation (SAARC) and developed plans for regional training on the use of biological control for fall armyworm management. Similarly, good links were established with GrowAsia, a regional organization mandated by the Association of Southeast Asian Nations (ASEAN) to develop a regional action plan on fall armyworm. CABI co-hosted and contributed to a webinar series, and in 2021 further virtual workshops will be organized, and plans will be developed for regional collaborative activities on biological control of fall armyworm.

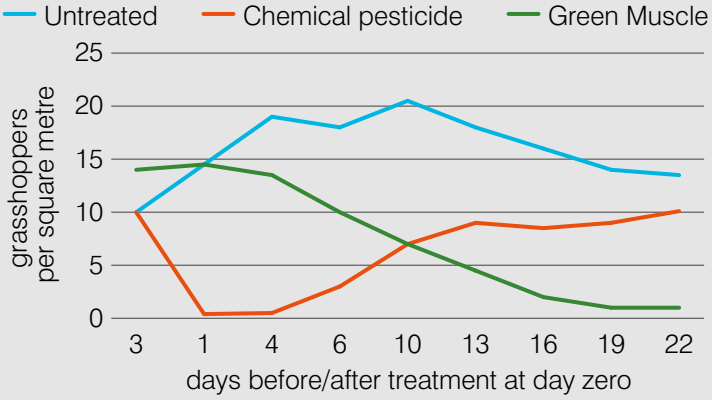
In Africa, close links were maintained with the African Union (AU), and the continental invasive species strategy previously developed was disseminated (including summaries in all AU official languages). The strategy will be tabled for formal adoption by the AU's Specialized Technical Committee on Agriculture, Rural Development, Water and Environment in 2021.

Green solutions to desert locust outbreaks

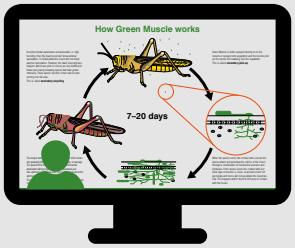
Despite widespread media attention around the recent desert locust outbreaks, there is little awareness of a proven biological control method for the pest that is safe and effective. Based on a naturally occurring fungus that attacks locusts, Green Muscle is one of two biological controls commercially available. Working closely with FAO and the private sector manufacturer, CABI has been raising the visibility of these green alternatives to chemical pesticides, to encourage greater uptake by national governments.

The core message

Field trials show that while a chemical pesticide (orange) can deliver immediate knock down, re-infestation soon occurs. Green Muscle (green) has a slower knock down, but remains effective for over 3 weeks, with no negative health or environmental impacts. (LUBILOSA data).



Spreading the message

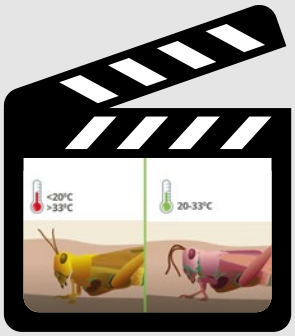


Virtual events

CABI hosted and participated in a number of online workshops, webinars and virtual conferences promoting green solutions to desert locusts, including at the World Food Prize.

Media coverage

Through targeted PR work, CABI's work on desert locusts had dozens of pieces of media coverage across the world, with over 157,000 estimated views.



Videos

A portfolio of 20 videos about Green Muscle was created, made available in English, French, Russian and Arabic, to explain how it works and how it is used.

Lessons learned

Activities in the stakeholder engagement work package usually require face-to-face meetings, so with restrictions on such meetings in many countries, a modified approach was required, involving greater use of remote and virtual interactions, literature and document review, and one-to-one interviews conducted by local consultants. While having some shortcomings compared to the usual way of working, the approach did succeed in delivering outputs, and this success will influence future plans even when travel and meeting restrictions are lifted.

The detection of apple snail in Kenya again highlights the importance of preparedness and response capacity, both for identified high risks as well as for unforeseen invasions. Nevertheless, governments are still reluctant to invest in prevention rather than response – which in the case of the apple snail increases the risk that it will spread to other rice schemes in Kenya and to other countries in the region. Apple snail can be expected to spread less rapidly than fall armyworm, so there is still an opportunity to mount a timely response.

Evidence of the potential losses caused by invasive species could contribute to investment in prevention as well as mitigation, and demand for this evidence is clear. However, generating rigorous and geographically comprehensive information, even for existing invasives, is challenging. Existing data on which to base estimates are limited, and novel modelling approaches that are scalable and cost-effective are likely to be required.

Next steps

Several of the aims and outputs of the Stakeholder Engagement work package will be part of CABI's new PlantwisePlus programme, so many of the activities reported here will be continued.

Stakeholders will be supported to engage in developing and implementing plans responding to species such as the apple snail, desert locust and *Prosopis*, according to priorities at local, national and regional levels, as necessary. Contingency plans will also be made for high-priority species that have not yet invaded focus countries.

Development and oversight of these plans will be promoted through the invasive species co-ordination mechanisms being established in the different countries. In some cases these come under the auspices of a national invasive species strategy, while in others they have emerged as a result of the system assessments. Ensuring the nascent co-ordination mechanisms are institutionalized and supported by the different stakeholders will be a priority. In Pakistan, the draft IAS strategy will be finalized, and a mechanism for its implementation will be agreed with stakeholders. Opportunities to link invasive species plans and strategies to climate change adaptation will be taken forward where possible.

Activities to address regulatory constraints to widening the use of lower-risk plant protection products will continue, including finding opportunities to streamline registration procedures and facilitate market entry for manufacturers and distributors of the products.

The study on losses due to invasives in Africa will be published, and a policy brief will be prepared on the multi-peril risk analysis in maize. Learnings from the different methods employed in the studies will be used to inform the GBCL assessment for maize, from which a protocol and initial set of loss estimates will be produced. The findings of the consultancy on governance of the GBCL initiative will be used to establish a governance framework to oversee the maize assessment and to develop plans for the first full round of global loss estimates.

Providing Best Practice Solutions for Invasive Species

Prevention, early detection and control of invasive species requires a set of technologies, methods and techniques that are efficient and effective for risk assessment, diagnostics, surveillance, eradication or suppression, and mitigation of impacts. Action on Invasives works with partners to strengthen capacities to develop, test and validate such solutions and practices through specific case studies.

Progress in 2020

Preventing invasive species: prioritizing potential invasive plant pests in Ghana and Pakistan

The prioritization of potential invasive plant pests in Ghana was initiated in 2019 and completed in 2020 by a group of around 20 national scientists. A ranked list was produced of potential invasives (invertebrates and pathogens) that are not yet present in Ghana, and which would be harmful to Ghanaian agriculture or forestry, or the environment, if introduced. For the highest-risk potential invaders, follow-up actions were identified, including PRA, prevention, surveillance and contingency plans (see next section below). A group of scientists also adapted the prioritization system to invasive weeds and listed species that would need attention and surveys of their potential presence in Ghana. A similar prioritization exercise was planned in Pakistan, but this had to be delayed and so was initiated at a smaller scale through online workshops, focusing on tomato pests and diseases as a training exercise.

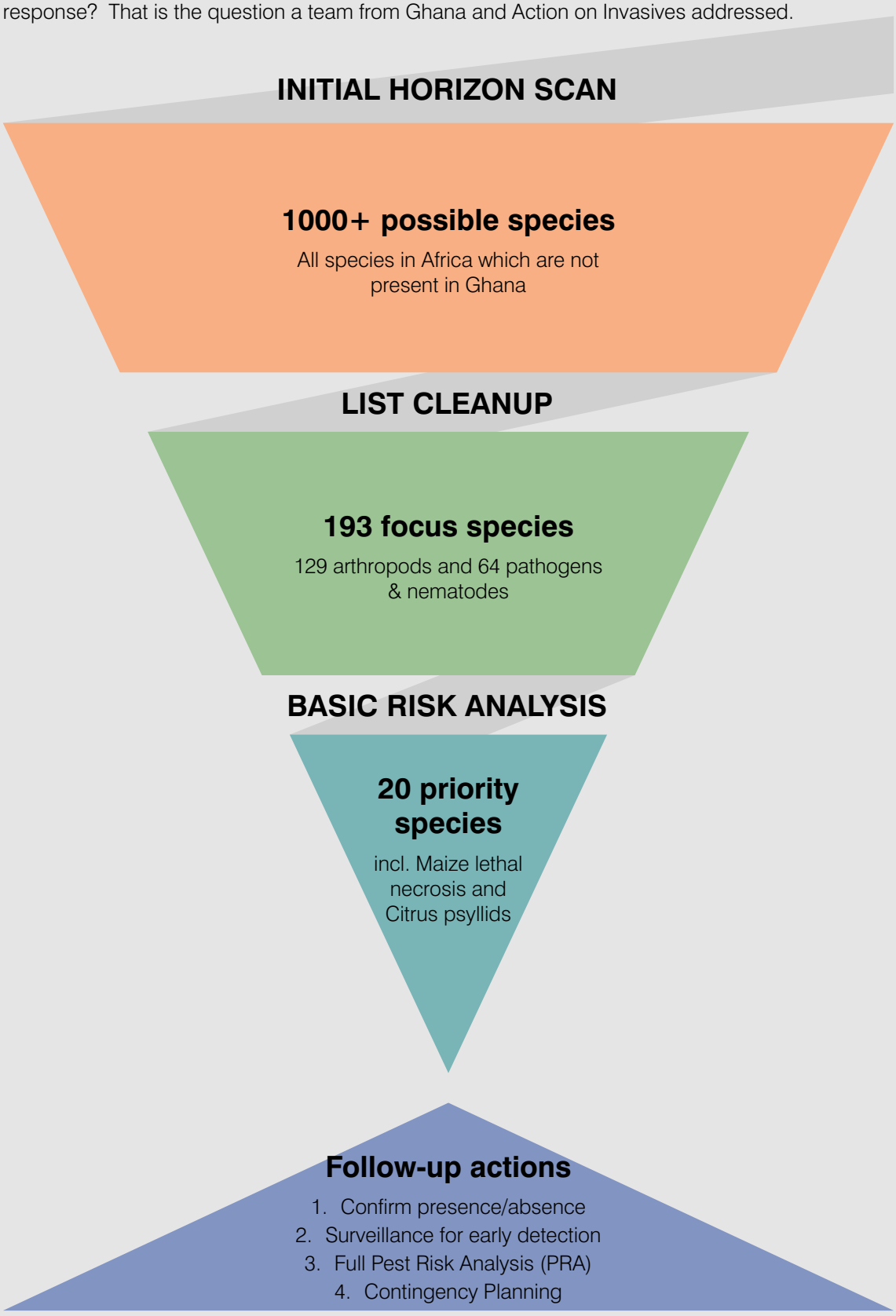
Detecting invasive species: surveillance and early warning/rapid response programmes

Following the prioritization project in Ghana, an immediate urgent action identified for the highest-risk species was surveys to assess whether the species might already be present in Ghana, or in the case of taxonomically complicated species, which biotypes are present or not. Surveys were carried out by the organizations involved in the prioritization; these focused on three insect genera/species (*Thrips* spp., *Liriomyza* spp. and *Bemisia tabaci*) and two pathogens (bacterial canker in tomato and cassava brown streak). Samples were collected in several regions, and are presently being analysed using molecular tools.

Following an earlier prioritization project in Kenya, similar surveys were carried out to confirm the presence and strains of four important invasive pathogens (*Dickeya* sp., *Pectobacterium atrocepticum*, *Xanthomonas citri* pv *citri* and potato spindle tuber disease). The surveys were delayed but they were completed in 2020 and the samples are now being analysed to identify species and strains.

Horizon scanning in Ghana

There are thousands of invasive species in the world that are absent from Ghana. But which ones pose the greatest threat and should be prioritised for prevention, early detection and rapid response? That is the question a team from Ghana and Action on Invasives addressed.



Also in Kenya, an early warning and rapid response procedure for the invasive tree *Prosopis juliflora* is being developed with communities in a conservancy. The tree is common and is still spreading in Kenya, so a community-level detection and response plan is appropriate. During the year, communication and training materials were developed through workshops and meetings, linked to an ongoing project on woody invasives (see Annex 1), and within the scope of the national management plan for *Prosopis*.

Controlling invasive weeds: biological control and IPM methods for parthenium in Pakistan

In 2020, research and development in this area focused largely on three biological control approaches to parthenium: the redistribution of the beetle *Zygogramma bicolorata*, monitoring the distribution and impact of parthenium winter rust (*Puccinia abrupta* var. *partheniicola)*, and importing another biocontrol agent, the beetle *Listronotus setosipennis*.

Rearing of *Zygogramma bicolorata* (parthenium leaf-eating beetle) continued during the year, with the aim of introducing it to areas in Pakistan where it is not yet present. Surveys of 2019 release sites were made, and over 2,700 more beetles were released at six sites in five districts. Surveys confirmed that the beetle has established itself at two sites in Faisalabad (central Punjab), but no evidence of establishment was found in four districts of southern Punjab. In Faisalabad it was also noticed that the beetle emerged from diapause earlier than in Rawalpindi. Based on these findings, ongoing releases will focus on central and northern Punjab.

Parthenium winter rust, was reported for the first time in Pakistan in 2019. Although the rust does not kill parthenium, it can reduce growth and seed production. Monitoring conducted in 2020 showed that the rust is firmly established and widespread. Because the main limiting factor is abiotic conditions, redistribution of the rust is unlikely to achieve a higher impact than has already been observed. The monitoring programme has proved beneficial in understanding where the rust is likely to have a high impact, and which regions are likely to require additional biocontrol agents.

Listronotus setosipennis is a stem-boring weevil from South America previously introduced for parthenium control in Africa and Australia. In the new quarantine facility at CABI Pakistan, tests were completed in which 22 plant species/varieties, including crops (eg sunflower) and native plants, were assessed for their suitability as hosts for *L. setosipennis*. The results were in line with those obtained in Australia, Ethiopia and South Africa, and *L. setosipennis* is considered safe for release in Pakistan. The application dossier for release was drafted and will now be sent for international review before submission to the relevant authorities in Pakistan.

A second year of field experiments was conducted to determine the damage threshold of parthenium in maize fields. Results show that it is not necessary to remove 100% of the parthenium to avoid yield loss, thus reducing the need for manual removal and/or herbicides. However, there is evidence to suggest that high populations of parthenium, even if removed from the field, could potentially have lasting allelopathic effects on crop germination and seedling establishment.

Controlling invasive species: biological control of fall armyworm using parasitoids and predators

Investigations on the three approaches to biological control of fall armyworm (classical, augmentation and conservation) continued in Africa and Asia. Field studies on the natural enemies of fall armyworm were conducted in Ghana, Zambia, Burkina Faso, Benin, Pakistan and Bangladesh, and more than 20 species of parasitoids and many predators were identified. Parasitism rates were sometimes found to be surprisingly high for a species that has invaded the two continents only recently; it was not uncommon to find over 40% of the larvae and 20% of the egg masses parasitized by native parasitoids. Conserving or encouraging this natural control is an important component of IPM.

The effect on natural enemies of spraying pesticides and biopesticides has been studied in Ghana over two years and results show that maize fields treated with emamectin benzoate had an average larval parasitism of 5.4%, as compared to 20.2% in the control plots, 9.9% in neem-treated plots and 19.7% in maltodextrin-treated plots. The effect of intercropping with cowpea,

groundnut and cassava on larval parasitism was also studied. In the first year the lowest parasitism rates were observed in maize monocultures (5.8%), with higher rates when intercropping with cassava (11.0%), cowpea (9.7%) and groundnut (12.3%). The effect of intercropping is also being studied in Zambia, as well as the effect of early planting. These studies indicate that intercropping and the planting date affect parasitism and damage levels (see below), but as parasitism is also dependant on the density of the host larvae, more trials are being conducted to disentangle these effects.

Augmentative biological control is being developed in Ghana, using the egg parasitoid *Telenomus remus.* A production system was set up in collaboration with the Plant Protection and Regulatory Services Directorate (PPRSD) and field trials were conducted in collaboration with the University of Ghana. Egg mass parasitism reached 33% in the major rainy season and 72–100% in the minor season, but similar parasitism rates were found in the control plots, suggesting they were too close to the treatment plots, so further trials are required. The mass production technique also needs improvement as it is currently too costly. *Telenomus remus* is also being reared in Pakistan for trials in 2021. In Bangladesh, CABI collaborated with the Bangladesh Agricultural Research Institute (BARI) to test two parasitoids that are commercially available in the country: the egg parasitoid *Trichogramma chilonis* and the larval parasitoid *Bracon hebetor*. Preliminary results suggest that neither species can provide sufficient control on its own.

Classical biological control of fall armyworm is progressing, though the pandemic has prevented collection of more parasitoids from Latin America. Two parasitoids, *Eiphosoma laphygmae* from Bolivia and *Chelonus insularis* from Nicaragua, are being reared in quarantine at the CABI Centre in Switzerland. During the year, rearing techniques were developed and host specificity tests were conducted. *E. laphygmae* has shown high specificity, as although it can attack congeneric species, the parasitoid does not develop. *E. laphygmae* females show little interest in other species of Noctuidae. This parasitoid is therefore considered the primary candidate for introduction into Africa and Asia. About 100 cocoons of *E. laphygmae* have been shipped to quarantine facilities in both Pakistan (CABI) and Benin (International Institute of Tropical Agriculture (IITA)), and the same number will be sent to Kenya (CABI, Kenya Forestry Research Institute) in 2021. The other species, *C. insularis*, is not yet ruled out because it is the main parasitoid of fall armyworm in the Americas. However, it is less host-specific, and can develop in other *Spodoptera* species. Studies on natural enemies of fall armyworm continue in Latin America through collaboration with Plantwise partners in Bolivia, Brazil, Peru and Nicaragua. If the pandemic allows, new strains of *E. laphygmae*, as well as other parasitoid species, will be imported for quarantine tests in 2021.

Controlling invasive species: a nematode-based control for fall armyworm in Rwanda

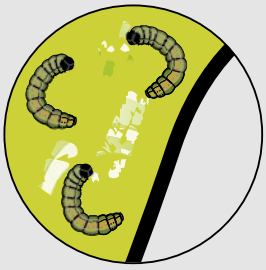
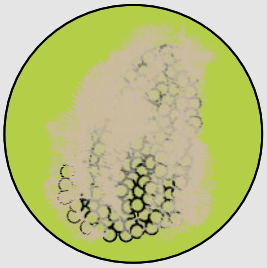
Research on the biological control of fall armyworm using EPNs, with the Rwanda Agriculture and Animal Resource Development Board and the University of Neuchâtel, is progressing well. Trials in 2020 showed that some EPN strains are highly effective against armyworm larvae. The study is now focusing on how to best incorporate EPN into a formulation that can be easily applied into the whorl of maize plants. In field trials in Rwanda, EPNs applied in a gel were found to be as effective as the chemical insecticide cypermethrin in controlling armyworm in naturally infested-fields. Both treatments reduced armyworm infestation within five to 10 days post-treatment by approximately 40% compared to the untreated control. A selective breeding programme to develop EPN with better tolerance to conditions on the maize plant has been initiated.

Controlling invasive species: other components of fall armyworm IPM

Trials on other components of IPM were undertaken under the growing conditions experienced by smallholder farmers in Ghana, Zambia and Kenya, in collaboration with national research organizations. In 2020 trials on cultural practices and biopesticides were conducted in parallel with the conservation biological control trials. In Zambia, a study on the influence of planting date found that early planting increased fall armyworm attack by about 100% compared to plantings made four weeks later, contradicting the widespread recommendation on early planting. Maize intercropping trials in Zambia and Ghana showed that intercropping can lower fall armyworm damage, but results varied with the companion plants and with the pesticides applied on the companion plants. In Zambia infestations were two to three times lower in maize intercropped with groundnut compared

IPM for Fall Armyworm

Action on Invasives has been researching all the IPM tools shown, together with public and private partners in Africa and Asia. Several tools are ready for use, with others in development. Registered products have satisfied efficacy and safety criteria.

Target Stage	IPM Tool	Description	Status
Adult 	Mating disruption	Releasing synthetic sex pheromone so males can't find females to mate	Registered in Kenya
	Intercropping	Planting other crops with maize	Some intercrops more effective than others
	Early planting	Maximises plant growth before armyworm arrives	Mixed efficacy; maybe context specific. Research ongoing
Medium larvae 	Entomopathogenic nematodes	Worms that infect and kill armyworms	Effective in field trials; formulations being tested
Small larvae 	Virus	Viruses that infect and kill armyworms formulated as a spray	Registered in several countries
	Neem	Botanical pesticide formulated as a spray	Registered in several countries
	Eiphosoma laphygmae	Parasitoid from Latin America for possible classical biological control	Host specific; application for release expected within a year
Eggs 	*Telenomus remus*	Parasitoid present in Africa with potential for augmentation	Trials in field and on cost-effective production ongoing

to maize monoculture or intercropped with cowpea. In Ghana, armyworm infestations were higher where cowpea was sprayed with a chemical insecticide compared to unsprayed intercrop or maize monoculture. In 2019 field trials in Ghana had shown that neem products were as efficient as chemical insecticides, and trials in 2020 found that a popular biopesticide based on a mixture of *Bacillus thuringiensis* (Bt) and a granulosis virus was similarly effective, even though the virus is from a butterfly and probably has no effect on fall armyworm. Results from trials in Burkina Faso are awaited. Fawligen (baculovirus) and Pherogen (pheromone for mating disruption) are now registered in Kenya, having been tested through Action on Invasives. All these results show that effective alternatives to chemical insecticides are available to control fall armyworm.

The assessment of biopesticide options for managing fall armyworm in Africa was updated and published during the year. For many biopesticides there is a growing body of information on their field efficacy and increased availability of commercialized products, though registration is still very uneven between countries. Information gaps include information about the compatibility of the biopesticides with other recommended management practices, and cost/benefit analyses, which are important for developing and implementing sustainable IPM.

Controlling invasive species: biological control for *Phthorimaea absoluta* in Ghana and Zambia

During the year, an MSc student from the University of Ghana completed surveys on the spread and impact of *Phthorimaea absoluta.* Damage by *Phthorimaea absoluta* was found to be severe in all seasons, and it was found that tomatoes cannot be cultivated without frequent application of pesticides. Two parasitoids and several predators were found, including parasitoids of the genus *Necremnus* and the predatory bug *Nesidiocoris tenuis*, which are used elsewhere in the world as augmentative biocontrol agents. While larval parasitism was negligible (1.6%) the predator *N. tenuis* was abundant, representing 55–75% of all predators. Furthermore, its abundance seems to be associated with lower prey densities. The same predator was also found by another MSc student supported by Action on Invasives, who studied its biology in the laboratory. Field and laboratory studies confirmed that this predator could be used as an augmentative biological control agent in Africa. Trials were also conducted in Kenya in collaboration with Koppert Biologicals Ltd. These included the use of another predatory bug, *Macrolophus pygmaeus*, commercially produced by Koppert.

The programme supported a Ghanaian PhD student to test Tutavir, a virus-based product specific to *P. absoluta* that could provide an alternative to chemical insecticides. Experiments were conducted and the data are presently being analysed.

Controlling invasive species: biological control of papaya mealybug in Kenya

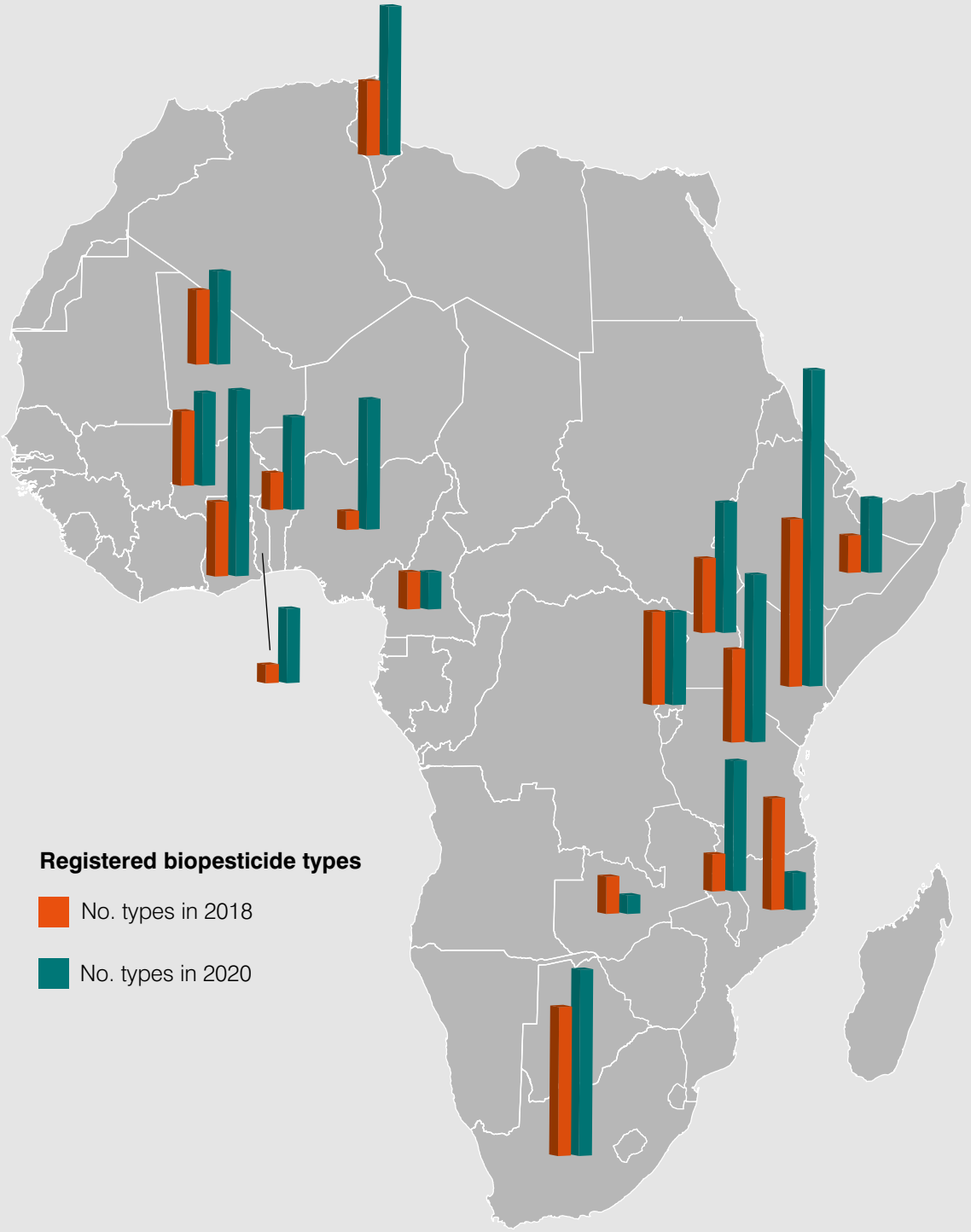
Surveys in 2019 showed that papaya mealybug is widespread and causing significant damage in Kenya, and that few indigenous parasitoids are attacking it. This justified consideration of biological control with the parasitoid *Acerophagus papayae*, which has been reported as effective in West Africa. An application dossier was prepared, and was used by Kenya Agricultural and Livestock Research Organization (KALRO) to secure an import permit for the agent from the Kenya Standing Technical Committee on Imports and Exports (KSTCIE). The parasitoid was obtained through field collections and subsequent rearing in Ghana by PPRSD and CABI. In late 2020 several hundred adults were imported to Kenya and a colony was established in the KALRO quarantine facility, where a papaya mealybug culture had been set up. The safety tests required by KSTCIE are in progress and field releases are planned for 2021.

Lessons learned

Some best practice solutions against well-known invasives, once they have been proven to be effective in one region, can be transferred to new countries. This is the approach being adopted for biological control of parthenium and papaya mealybug in Pakistan and Kenya, respectively, and such opportunities could be more frequently considered in the future. For example, several invasive weeds in different parts of Africa have been the subject of biocontrol programmes elsewhere, from where the agents could be introduced, provided the regulatory process is not prohibitive.

Biopesticides for fall armyworm in Africa

New types of biopesticide (active ingredient) have been registered for use against fall armyworm in many countries since 2018. But in some countries farmers still have little to choose from if they want a lower risk plant protection product. Data shown for selected countries only.



2018 to 2020 changes

1.7x as many types registered

2x as many registered products

On the other hand, developing best practice solutions for newly invasive species such as fall armyworm requires time-consuming and sometimes costly research activities with uncertain outcomes, because methods that are effective in native areas or on other continents are not necessarily suitable in a newly invaded continent. The fact that there are few immediate solutions for new invasive species, and that some approaches that are tested will fail, needs to be taken into consideration. Initial recommendations for farmers therefore have to be based on scientists' expertise and evaluation of whatever information is available, rather than on the results of trials. As research programmes yield results, recommendations can be updated or amended.

Research for development, in particular against invasive species affecting many countries, proceeds more rapidly with close and open collaboration. Yet national and international research organizations involved in development programmes can be competitive and reluctant to collaborate and share results, which slows the development of new solutions. The desire to show positive outcomes can also result in organizations and researchers hiding negative results, again slowing overall progress.

The development of best practice solutions in plant health and invasive species management should always involve an assessment of their cost-effectiveness and acceptability. However, the benefits of lower-risk approaches are often external to the farmer choosing a control method, so policy options need to be investigated that take account of environmental and health costs and benefits.

Next steps

As Action on Invasives is merged into PlantwisePlus, several of the anticipated next steps will be implemented under that programme. Surveys and surveillance programmes that have been initiated after the prioritization activities in Kenya and Ghana will be completed, and further actions will be taken based on the lists of priority species, such as pest risk analyses, surveillance programmes and contingency plans for high-risk species. The prioritization of potential pests of tomato initiated in Pakistan in 2020 will be completed and further actions will be taken based on the list of priority species. More prioritizations will be conducted in new countries.

The work on classical biocontrol against parthenium weed will continue in Pakistan, with an application to release the weevil *Listronotus setosipennis*. In view of the possible release in 2021, appropriate release sites will be selected, and long-term monitoring plots will be established to determine weevil survival and impact following release.

Augmentative biological control techniques that have been developed using egg and larval parasitoids of fall armyworm will be improved and, if successful, will be applied in farmers' communities in Africa and Asia. Investigations on methods to conserve and enhance the parasitoids and predators of fall armyworm shown to be important in smallholder maize cropping systems will continue in Ghana, Zambia and Burkina Faso, and will be initiated in Pakistan and Bangladesh.

The risk assessment for the fall armyworm parasitoids *Eiphosoma laphygmae* and *Chelonus insularis* will be completed in Switzerland, Kenya, Pakistan and Benin, and petitions for releases will be prepared, starting with *E. laphygmae*. Further collections will be carried out in Latin America to refresh the laboratory cultures of the two species and to collect new parasitoid species for further studies.

Work will take place in Rwanda on the use of EPNs against fall armyworm, focusing on the improvement of the gel formulation and its application, as well as identifying fall armyworm feeding stimulants to increase the efficacy of the formulation.

Methods for using predators and parasitoids of *Phthorimaea absoluta* in African farming systems will be further developed and implemented in Ghana. The parasitoid *Acerophagus papaya* will be released in Kenya, once the last tests have been conducted and a release permit obtained. Requests have also been received from other African countries to release the parasitoid, so support will be given to these where possible.

Community Action: Bringing Information and Action to Scale

This work package aims to achieve large-scale implementation of best practice solutions, adapted to community contexts and needs. The programme works in partnership with rural communities and local actors to understand the socioeconomic context, strengthen extension and advisory activities, facilitate the widespread uptake and adoption of appropriate control practices, and document the impacts of invasive species and the benefits to communities of managing them.

Progress in 2020

Understanding farmer contexts

A gendered technology analysis was undertaken to understand the experiences of women and men farmers in the communities participating in the area-wide piloting of biological approaches to fall armyworm control in Kenya. Through individual interviews and focus group discussions the aim was to identify gender-related issues and opportunities for promoting uptake of non-chemical control methods. All the control methods were reported to be at least partially effective in reducing crop loss, but compared to spraying pesticides the control methods reduced the time and labour required, though to varying degrees. Pherogen (mating disruption product) was particularly attractive for women farmers, as it does not require a knapsack sprayer, use of which is difficult for women, or costly if they hire labour instead. Some women farmers reported that the reduced time spent controlling fall armyworm enabled them to spend more time cultivating vegetables for household consumption. Other control methods, including Fawligen (virus-based biopesticide) and *Metarhizium* (fungus-based biopesticide), were also positively rated by women because of the reduced frequency of spraying. However, respondents reported that access to these products is still limited, either because they have only just been registered, or because the higher price reduces demand so local retailers tend not to stock them.

A household survey was conducted in Ghana to determine how farmers are coping with fall armyworm and its management. Of the 1,435 households surveyed, 370 had also been surveyed in 2018, allowing changes to be evaluated (see the section on monitoring and evaluation). The survey also provided detailed information on what farmers do and why. Over 50% of farmers use pesticides (including biopesticides) for reasons that include their efficacy (77%, higher than for all other methods) and because they are donated by the government (37%). The five most widely used pesticides are all biopesticides or the recommended emamectin (shown by programme trials to be effective), with the exception of the most commonly used product (20% farmers), which is a

mixture of *Bacillus thuringiensis* (biopesticide) and monosultap, an active ingredient in the category of nereistoxin analogues. Monosultap is not widely used except in China, and is not listed in the WHO Classification of pesticides, but its toxicity is similar to moderately hazardous compounds. Although over 70% farmers reported using at least one item of personal protective equipment, less than half of farmers use masks, overalls, gloves or a head covering. Female farmers use masks, gloves and head coverings significantly less than males. A range of agronomic practices are also widely used, including frequent weeding (80%), timely planting (71%), applying fertiliser (35%), intercropping (26%) and crop rotation (25%), all of which were perceived to be effective by over 50–70% of farmers. Female farmers generally use similar control methods to those used by males, but they use intercropping and pesticides significantly more often than males. Intercropping and the use of ash (homemade pesticide) is more common in smaller farms or poorer households, while applying fertiliser is less frequent.

A telephone survey of farmers who participated in training on and demonstration of IPM practices for *Phthorimaea absoluta* in Kenya showed that they had good understanding of the biological control options (pheromone traps, sticky traps and *Trichoderma*). The key benefits of using biological control methods as reported by farmers were reduced pesticide sprays, contributing to safer food (50%), reduced expenditure on pesticides (48%), and less labour input (48%). Farmers reported average expenditure on pesticides and labour each decreased by just over 40%.

Reaching farmers through communication campaigns

During the year, communication campaigns on fall armyworm, parthenium, tomato pinworm and papaya mealybug were conducted, often jointly with Plantwise and other projects, in Ghana, Kenya, Zambia, Pakistan and Bangladesh. The table in the monitoring and evaluation section below shows the numbers reached through actual counts or conservative estimates, totalling over 900,000.

As has previously been the case, campaign materials drew on technical briefs prepared with partners to maintain consistency of messaging. A technical brief on papaya mealybug for Kenya was developed containing information on papaya mealybug identification, prevention, monitoring and management. In Pakistan a technical brief was prepared for fall armyworm.

The campaigns on fall armyworm in Ghana and Zambia used SMS to re-enforce the earlier campaigns, with an emphasis on agronomic practices, scouting for early detection, and safe and responsible use of pesticides. This was based on lessons learned from previous campaigns and gaps identified during the summative appraisals. In Zambia another SMS campaign was initiated at the end of the year, targeting about 80,000 farmers in the 2020/2021 cropping season.

In Kenya, a radio campaign on papaya mealybug was implemented, focusing on the coastal area where papaya is most frequently grown. The campaign aired on the local Radio Kaya and included: one-hour talk shows for six consecutive weeks, in which experts responded to farmers' queries; sponsorship messages for four weeks, with direct messages emphasizing key points from the talk shows; and short features (less than five minutes), elaborating on specific topics such as identification of papaya mealybug, preventing spread, and management using natural enemies. An after-action review was conducted with partners to learn lessons from the activity to inform future communication activities on the management of papaya mealybug and other invasive scale insects.

In Pakistan, a virtual workshop for over 70 participants reviewed and endorsed the technical brief and a pest management decision guide for fall armyworm. Pest management decision guides were also prepared/updated for parthenium and tomato pinworm, and translated into Urdu. Over 160,000 parthenium and fall armyworm printed extension materials were distributed to extension workers and farmers and through partners' trainings and events. A total of 26 training of trainers sessions were conducted across Pakistan for government and private partners, on the basis that trainees would then initiate awareness campaigns in their respective areas as part of their regular farmer training programmes. Youth in universities and agricultural training institutes of Punjab province were sensitized on management of parthenium, and were provided with flyers and videos for further sharing. The awareness sessions were covered by many national and local news TV channels and also shared on social media, including Facebook and YouTube.

As part of the broader awareness campaign, a stand on invasives, including parthenium, was staged at the Pakistan Horti Expo 2020 in Lahore. And the construction of a diorama on invasive species was completed at the Pakistan Museum of Natural History in Islamabad, which is visited by around 100,000 people a year, including school children.

In Bangladesh, SMS messages and a video on fall armyworm management were developed in collaboration with International Maize and Wheat Improvement Centre (CIMMYT) and translated into Bangla. They were disseminated by the Agriculture Information Services (AIS) Bangladesh through national TV and community radio channels, and soft copies of videos were distributed among training course participants. Over 50,000 fall armyworm leaflets were distributed to farmers in 12 districts. Eight Training of Trainers sessions for agrodealers were organised with the Agriculture Advisory Services (AAS).

Facilitating access to best practice solutions

In Ghana and Kenya, seven communities (4 in Ghana and 3 in Kenya) developed and implemented area-wide management plans for the control of fall armyworm. Over 400 farmers participated in the activities that included synchronized planting, routine monitoring, field sanitation, use of cultural practices and biological plant protection products such as neem for fall armyworm management. End-of-season surveys showed that participation in area-wide management activities improved farmer knowledge on fall armyworm management, including identification of fall armyworm egg masses, routine monitoring, agroecosystem analysis, natural pest regulation using natural enemies, and the effect of the weather on fall armyworm. In Ghana, 200,000 *Telenomus remus* parasitoids were released in the four communities, as part of the development of augmentative control.

Demonstration trials of IPM practices for tomato pinworm were conducted in Kenya in partnership with Koppert Biologicals Ltd; these included the use of a predatory bug (*Macrolophus pygmaeus*) and a pheromone trapping system. Over 1,000 farmers and extension workers participated.

In Pakistan, rural communities were engaged through the Punjab Rural Support Programme (PRSP). Activities were carried out in the three main maize-growing districts of Punjab, targeting 96 village organizations. Due to the pandemic, activities took place later than planned, but PRSP staff completed community engagement by the end of October. This included providing information on private sector vendors of pheromone traps and lower-risk pesticides, so communities can include these options when making their fall armyworm management plans.

Previous work in Kenya had shown that one reason farmers do not use lower-risk pesticides is because they are not readily available. A survey of 1,300 registered agrodealers in 44 counties was conducted with partners. It found that availability is very varied. In 15 counties agrodealers sold over 30 pesticide products for fall armyworm management, but in five counties only five such products were sold. The four most commonly sold products were alpha-cypermethrin, lufenuron, chlorantraniliprole+abamectin and flubendiamide. Of these, only chlorantraniliprole is recommended by the FAO Global Action technical committee. Very few biopesticides were found to be on sale.

Some of the lower-risk control products for fall armyworm and tomato pinworm are based on baculoviruses, but these are often more expensive than synthetic pesticides, with which they compete. Working with Andermatt Biocontrol, a possible approach is being investigated that could enable farmers to use a virus product at lower cost. In the proposed model, farmers would purchase a virus starter kit, perhaps once a season, apply it to the target insect, and then collect the diseased and dead larvae, from which a concoction can be prepared containing the virus for subsequent application. Maintaining the quality of the virus is important, so small-scale trials have started to develop low-tech methods for multiplication of the virus.

Lessons learned

A cost-effective approach to communication campaigns is to work through organizations that already have communication systems and infrastructure, such as databases of farmer profiles. Other organizations may already have face-to-face interaction with farmers, and at least in some cases (as found in Pakistan) this is more cost-effective in changing attitudes and practices, even if the cost per person reached is higher. Thus, although the pandemic has accelerated the use of other communication methods, the role of extension officers meeting farmers is still important.

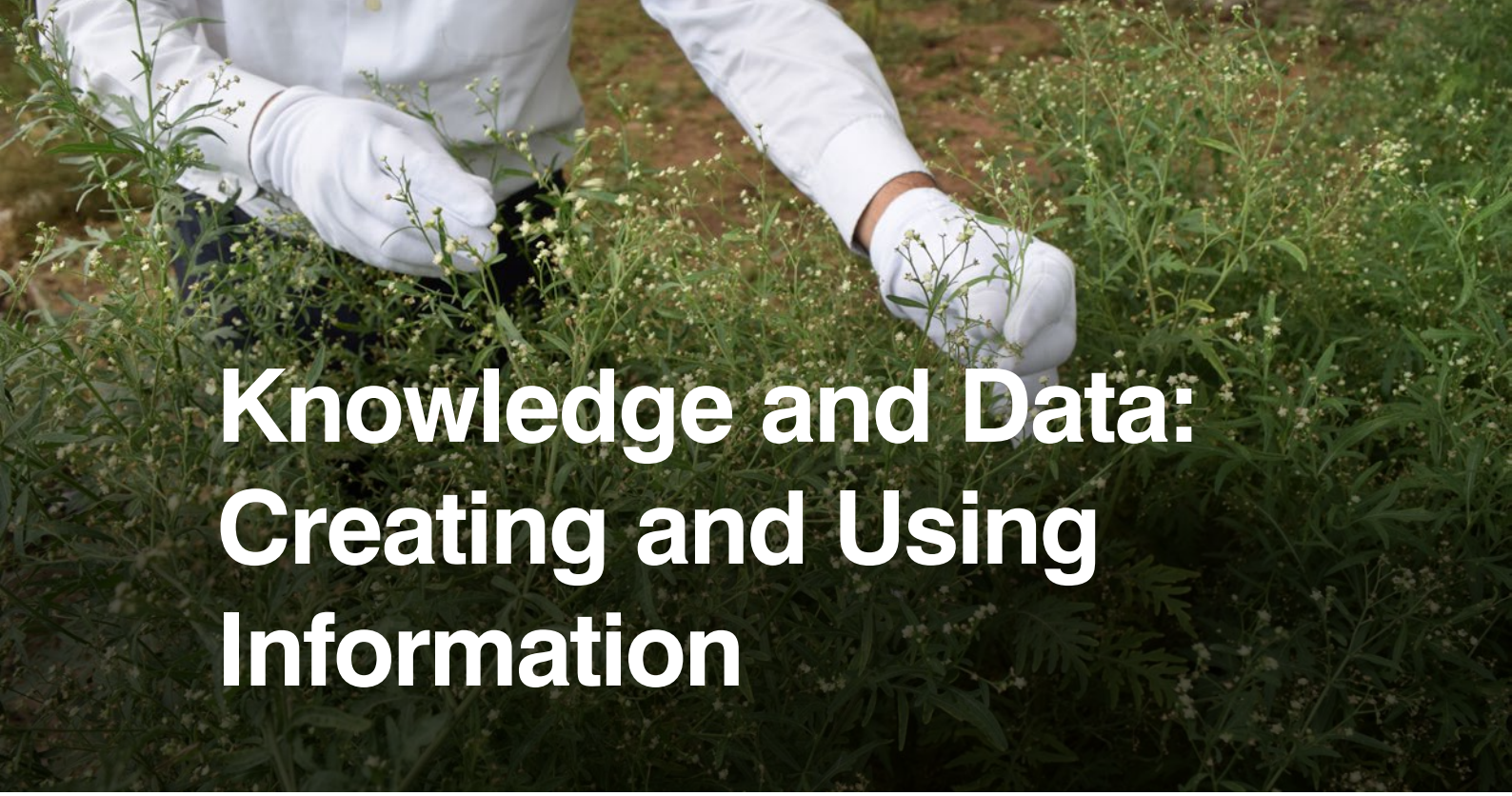
Farmers everywhere have a propensity to manage invasive pests using pesticides. Work this year and previously has shown that there are several related factors contributing to this tendency, and it is likely that addressing them piecemeal will not be effective. For example, many farmers are aware of the dangers of synthetic pesticides, yet the use of personal protection equipment is still relatively low, so raising farmers' awareness is insufficient. If prices of lower-risk products are too high, then demand is lower, and retailers will not stock the products, which are therefore not available for farmers to buy even if they want to do so. And if the expected market is small, the costs of registering a low-risk product may dissuade manufacturers from entering the market.

While the area-wide management activities conducted this year provided a forum for farmers to jointly plan and implement management options that are within their means, the implementation was still relatively limited in geographical coverage. There is a need for increased sensitization of local extension personnel to scale up this approach over larger areas.

Next steps

Communication and awareness activities are a key component of improving the way in which farmers and communities manage invasive species, and will be continued under PlantwisePlus, building on the experience of Action on Invasives and Plantwise. Surveys to understand the decisions farmers make, the losses they sustain, the costs of management, and the overall impacts of invasive species, and interventions to manage them, will continue to inform the new programme.

PlantwisePlus will also seek to address both demand-related and supply-related factors that inhibit the use of lower-risk plant protection products. This will include greater engagement with the private sector, and further development of local or community production of biological plant protection products, such as microbial pesticides or macrobial biocontrol agents for augmentative control.



Knowledge and Data: Creating and Using Information

This work package develops processes to create, exchange and use online/offline content, information and data at the regional, national and local levels. Novel information tools have been developed to support diagnosis, risk analysis and regulation using globally relevant information resources and complementing Plantwise processes. These new tools are fully integrated into CABI's existing information infrastructure, to allow for the most efficient delivery to meet the needs of end users.

Progress in 2020

Enhancing the PRA tool

The PRA decision support tool, which uses data from CABI's Crop Protection Compendium to help risk assessors to complete pathway-initiated and pest-initiated PRAs, was enhanced to improve the functionality and user experience. A user survey was carried out and a series of online interviews were conducted with PRA experts from several organizations (US Department of Agriculture, APHIS, CFIA, CAHFSA, DEFRA, IPRRG, FAO) to prioritize user feedback and identify enhancements. Releases of improvements and new features took place throughout the second half of 2020. One of the major new features, and the most commonly requested by users, is the ability to share a PRA in progress between multiple users. An online sharing function was developed allowing a team to be created who can all contribute to a specific PRA. For team members without access to the tool, an additional option was developed allowing an offline version of a PRA to be shared for editing and subsequent import back into the tool. Other significant enhancements include the facility for users to maintain a list of regulated pests, the ability to exclude entire pest groups from the PRA, new sections considering the effects of climate, and an option for users conducting a pathway-initiated PRA to carry out a rapid preliminary assessment of species, to focus the list of pests on just those that need a full assessment. Some sections of the PRA can now pull information on distribution, taxonomy and potential impact directly from the relevant Crop Protection Compendium datasheet. A short, self-guided tour was also included in the tool to demonstrate its features and functionality. Gratis access to the tool was reviewed and was extended for another year to NPPOs in 97 low- and middle-income countries, but opportunities for income generation continue to be sought, to secure sustainability.

Fall Armyworm Research Collaboration Portal

Following a scoping study on the development of an online fall armyworm research collaboration portal, an international steering committee of organizations involved in fall armyworm research was formed to guide the direction of work, and to ensure that other initiatives were taken into consideration. A survey of researchers working on fall armyworm was carried out to ascertain what tools the fall armyworm research community were already using in their work, what additional requirements they had for sharing their research, and what barriers they had to sharing data and information about their research. This feedback showed the need for a flexible platform allowing researchers to share short updates on their research, with the option to include datasets, images or documents. The challenge of getting researchers to share unpublished information was also highlighted by respondents. The Fall Armyworm Research Collaboration Portal (**faw.researchcollaborationportal.org**) was launched in June 2020 and promoted through various channels, including webinar presentations, posts on social media, other social platform groups, and a monthly newsletter. The portal was endorsed by the CIMMYT and IITA-led Fall Armyworm R4D International Consortium and the FAO Global Action for Fall Armyworm Control, and GrowAsia used the portal to promote and invite questions for the ASEAN Fall Armyworm Action Plan webinar series. A group of six "Research Champions" was recruited to drive engagement in the different research areas. The portal now has over 600 registered users and has received more than 16,000 visits in the six months since its launch.

Upgraded invasive species knowledge platform

The ISC (**www.cabi.org/isc**) was further enhanced based on user surveys and site usage analytics. Several improvements were made to the distribution maps, which are one of the most used and valued features. New filters allow users to toggle the display of different datasets, filter within a dataset, and display additional information on the map, such as the extent or status of a species' presence within a country, rather than just presence or absence. Feedback and analytics also showed that, particularly for extensive datasheets, navigating to the specific information needed can be difficult, particularly when accessing the ISC from a mobile device. Datasheet sections were therefore made collapsible, with the most frequently used sections visible as default. Additional enhancements included an improved search functionality on the species portal pages, as well as the incorporation of an advanced datasheet search.

Following confirmation of the presence of the invasive snail *Pomacea canaliculata* in Kenya, an apple snail portal was added to the ISC, in anticipation of demand for information from other countries in Africa that are at risk. The four existing portals were updated with new content and data, including new management factsheets developed under the Community Action work package. Ten new datasheets on invasive species were commissioned and published under the programme in 2020 (aside from those commissioned by associated projects described in Annex 1), and 2,500 datasheets were updated with new information or data. In 2020 there were over 3.4 million visits to the ISC, a 66% increase over 2019, due in part to search engine optimization. An evaluation of the ISC found that it is highly valued for its reliable and current information, and for being open access (see the section on monitoring and evaluation).

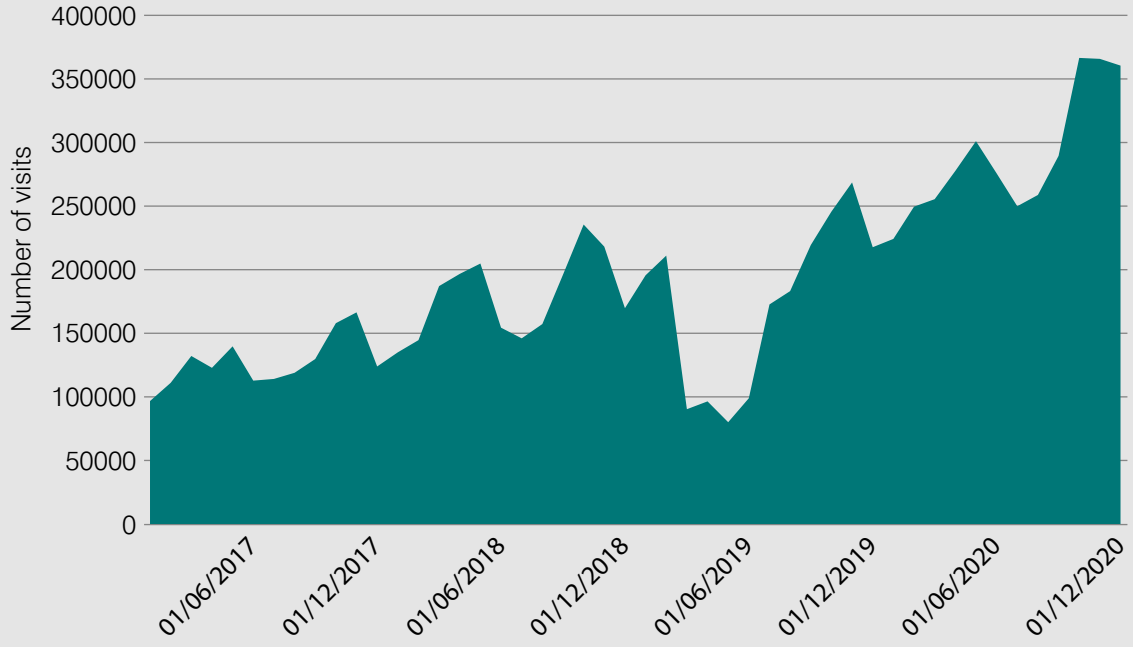
Integrating new datasets into the distribution database

The distribution database that underpins the ISC, the PRA tool and the Horizon Scanning Tool, was upgraded to improve the bulk uploading of datasets, including a species name matching tool to reduce the time required for managing synonyms in taxonomy when importing data from third parties. Three large datasets were uploaded, including distribution data from the European Plant Protection Organization and a large dataset generated under the Plantwise programme from text mining of journal articles in CABI's bibliographic database CABDirect (**www.cabdirect.org**). More than 50,000 new distribution points were imported, which have provided updates to 2,500 species in the database. The distribution database is now fully integrated into workflows, allowing more rapid updates as new datasets are identified or become available.

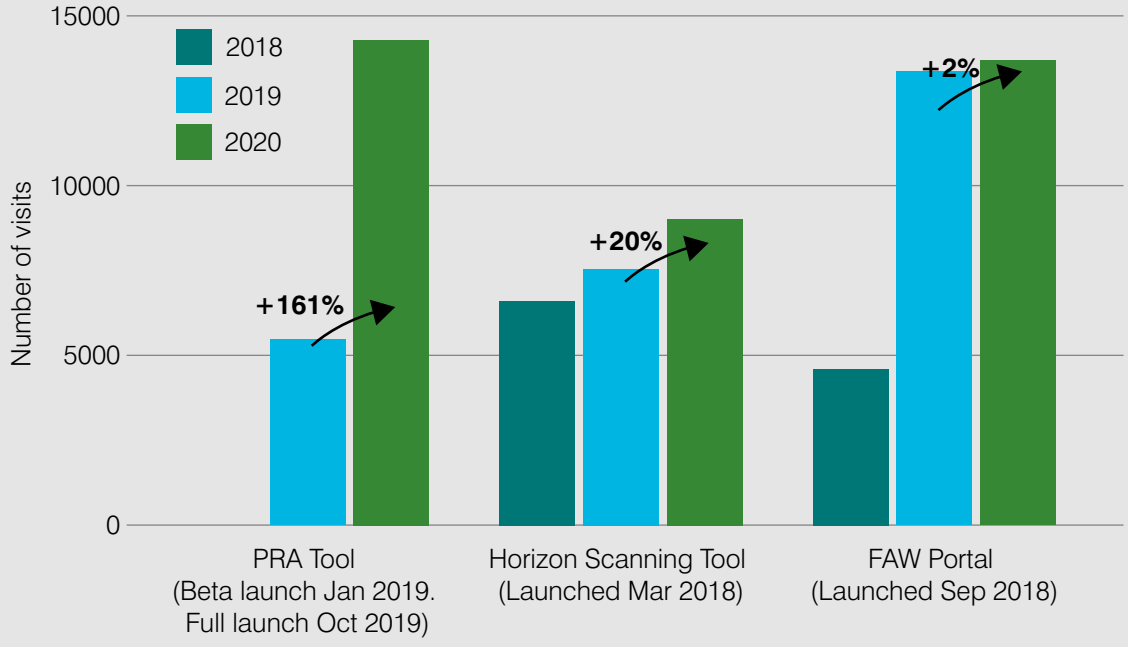
Knowledge tools for managing invasive species

Evaluations of the invasive species compendium (**www.cabi.org/ISC**) show it is valued for its up-to-date, reliable, and detailed information. So use of the compendium and the associated tools is increasing.

Monthly visits to the Invasive Species Compendium



Annual visits to knowledge tools



Promoting and expanding the data management system

In 2020 the CABI open data management website (**https://ckan.cabi.org/data/**) began issuing datasets with Digital Object Identifiers (DOIs), which allows published data to be easily cited. Additional datasets, as well as relevant documentation related to data work, were uploaded to the system, including the Action on Invasives Data Policy and Strategy. Two workshops were conducted remotely with CABI centres to promote the use of Open Data Kit (ODK), which links to the system. A cross-centre group of CABI staff involved in digital development and data collection and management was engaged to promote the use of ODK and the information system with partners. Other CABI projects are now also making use of these tools and processes, as are some partner organizations.

Lessons learned

Despite the consensus among researchers that open data practices and collaboration can benefit research efforts, particularly for a new invasive species such as fall armyworm, there are still significant barriers to this happening. The Fall Armyworm Research Collaboration Portal provides an online platform for researchers to share and begin discussions, in line with their expectations and requests. But, despite that, most visitors to the portal are looking for information rather than sharing it, with just 12% of the registered users posting their own contributions. Having a team of dedicated "Research Champions" has improved engagement, and has also highlighted important concerns around data permissions, confidence in the research, and time constraints. CABI is making efforts, through other data sharing advocacy projects, to address these barriers, but they are particularly significant in relation to timely response to a new invasive species.

One area affecting sharing of data is the incentive for individuals to do so. If incentives are not clear enough, or are not thought to outweigh the perceived risks, scientists are unlikely to make unpublished information available. However, there is increasing demand from journals for datasets to be shared as a condition of publication. The CABI open data management website allows research datasets generated by CABI or other organizations to be quickly and easily uploaded and assigned a DOI to fulfil this requirement. CKAN can also be a place for sharing relevant documents that benefit from having a DOI.

NPPOs in 97 countries have been given gratis access to the PRA tool and the Crop Protection Compendium (to be increased to 112), although several have not used this access. One reason for this may be that countries are not undertaking PRAs, due to inadequate capacity. Existing users have highlighted this issue. The tool was not originally designed for training purposes, but information and help has been added to support inexperienced risk assessors. In addition, CABI has joined an IPPC PRA e-learning working group, and through an MoU is working with COLEACP to develop PRA e-learning resources that can support risk assessors to conduct PRAs. By exploring opportunities where the PRA tool can be used as part of PRA capacity building, the tool will be made available to as many risk assessors in low- and middle-income countries as possible.

During the year, the PRA tool was successfully enhanced with many new features beyond the initial plans, as additional resources became available due to the scaling back of other programme activities. One reason the development work went smoothly was the excellent communication between all roles in the project team. Requirements were clearly specified, responsibilities were understood, and there was a defined escalation process through which issues were quickly addressed by the "product owner". The open culture of the team allowed members to challenge designs and decisions, which ultimately led to better outputs. A more detailed "lessons learned" retrospective of the PRA tool project is being compiled, as a case study of a highly successful IT project.

Next steps

The Horizon Scanning Tool and the PRA tool will continue to be supported and used through CABI's new PlantwisePlus programme, under the objective "Strengthening systems for detection and response to pest outbreaks". The e-learning resources being developed through the collaborations with COLEACP and IPPC will also be used in PlantwisePlus activities.

The impact of the Fall Armyworm Research Collaboration Portal will be reviewed in early 2021. A user survey will be conducted and the international steering committee will be consulted about the future of the portal. The platform has been set up to incur minimal maintenance costs so it could be supported by CABI or taken up by another organization if appropriate. The portal was developed with future opportunities in mind, and could be used as a basis to quickly develop a similar platform for another invasive or topic of research.

Developments completed as part of improvements to the ISC reduce the time required to update datasheets with data from large external datasets, so that any distribution data updates are reflected across all the tools simultaneously. Text mining will continue to be used to capture distribution and host data from published articles, and a new workflow will be developed in early 2021 to ensure that these data are used by CABI's decision support tools as quickly as possible. Species portals in the ISC will be reviewed annually for their relevance, and new portals will be created in response to need as new problems emerge.

The distribution database has opened up new opportunities to be explored for CABI to make use of different datasets and to deliver them to a wider audience. For example, there is a wealth of data available on the Global Biodiversity Information Facility (GBIF) which could be used in CABI decision support tools, either by importing into CABI's distribution database or feeding directing into the newly enhanced maps in the ISC.

Monitoring and evaluation

The Action on Invasives logical framework contains indicators for each output (work package), and progress against these has been reported in the preceding sections. The programme's purpose is to strengthen system capacity to prevent, eradicate, control and manage priority invasive species at the local, national and regional levels. Three indicators are identified for this purpose or outcome:

- the number of men, women and youth utilizing and/or benefiting from best practice solutions
- the number of countries using invasive species knowledge and data to inform operations for invasive species management
- the number of countries/regions that are more responsive to invasive species threats and the need to implement control measures

Number of men, women and youth utilizing and/or benefiting from best practice solutions

The number of people benefitting from best practice solutions depends in part on the number of people receiving information on those practices. The table below summarizes the reach of the communication activities in 2020, which totalled 933,388 people. In several cases this work was conducted jointly with Plantwise or other projects.

Table 1: Estimated reach of 2020 communication activities

Country	Campaign	Reach figure calculation	Total[1]	Male	Female
Ghana	SMS messages to maize and tomato farmers	Based on delivery reports of messages sent	16,630	4,262	2,765
Kenya	Papaya mealybug radio campaign	200,000 listenership Households = six people. Two-thirds assumed to be adults 78% of listeners are in rural areas = 156,000 92% growing pawpaw = 143,520 Of these we can estimate that two-sixths (or one-third) listened = 47,835	47,835		
Zambia	SMS messages to maize farmers 2019–2020	Same calculation method as previously	79,493	39,270	40,223
Bangladesh	Radio, video and printed materials	Households growing maize = 1,040,000. BTV broadcasts throughout the country Conservatively, we can estimate that 70% of these have TVs = 728,000 BTV is watched by 43% of viewers = 313,040 Household size would indicate that there are two adults per household, which results in reach of 626,080	626,080		
Pakistan	Fall armyworm and parthenium training of trainers	In-person training	702	640	62
Pakistan	Fall armyworm and parthenium Farmer Field Days	In-person training	5,389	3,540	1,849
Pakistan	Fall armyworm and parthenium social media	Facebook (using clicks figures) 140,066 YouTube channel views – 10,658	150,724		
Pakistan	Women and youth	In-person training	965	722	243
Pakistan	Horti Expo stand	Number of visitors	5,296	4,065	1,231
Pakistan	WhatsApp group	Group participants	274	244	30

[1]Total individuals disaggregated where data permit. Gender was not reported for 9,603 individuals in the Ghana campaign

Two evaluations of communication campaigns were undertaken. In Pakistan an external evaluation was conducted of the previous year's mass extension campaign on parthenium, comprising a survey of 700 individuals, key informant interviews and six focus group discussions with farmers and their local communities (four with men, two with women). The evaluation showed that awareness and knowledge about parthenium in the sampled districts had increased, and a large number of respondents reported having shared information about parthenium with others. As people tend to share information that matters to them, the results indicate that attitudes to parthenium are being changed. This resulted in fewer farmers feeding parthenium to their livestock, and greater adoption of control methods, particularly weeding. Communication through extension workers and experts, via face-to-face meetings and live events, was found to be the most cost-effective method, as compared to mass media methods, such as public service messages on TV, radio, newspapers and social media. The approach of engaging intermediary organizations, such as extension departments, universities, schools and NGOs, was found to be appropriate. However, the evaluation highlighted that some people continue to believe that parthenium has a medicinal value, particularly for people with diabetes.

In Zambia an evaluation was carried out of the SMS campaign on fall armyworm management through a telephone survey of 3,000 farmers. The evaluation was implemented as a joint activity with the Plantwise and PRISE programmes; analysis is ongoing and will be reported elsewhere.

In Ghana a survey was conducted among 370 households who were also surveyed in 2018, allowing an assessment of changes that have occurred in the way farmers manage fall armyworm. In general, households were found to be using more control methods, but the major change was the increased adoption of cultural practices. Synthetic pesticides were still being used by over half of farmers, but more farmers who used pesticides were using the recommended emamectin (alone or in mixtures). The use of biopesticides was found to have increased slightly, while the use of the chemical pesticide lambdacyhalothrin had declined. Perhaps the most important change in pesticide use was the 38% reduction in average number of sprays per season, from 2.45 to 1.52, with a 44% reduction in the amount spent on pesticides. The cost of the agronomic practices used was not determined, so it is not possible to say whether overall farmers were spending less on managing fall armyworm than they were in 2018. However, it is clear that farmers had changed their management actions, broadly in line with recommendations.

Number of countries using invasive species knowledge and data to inform operations for invasive species management

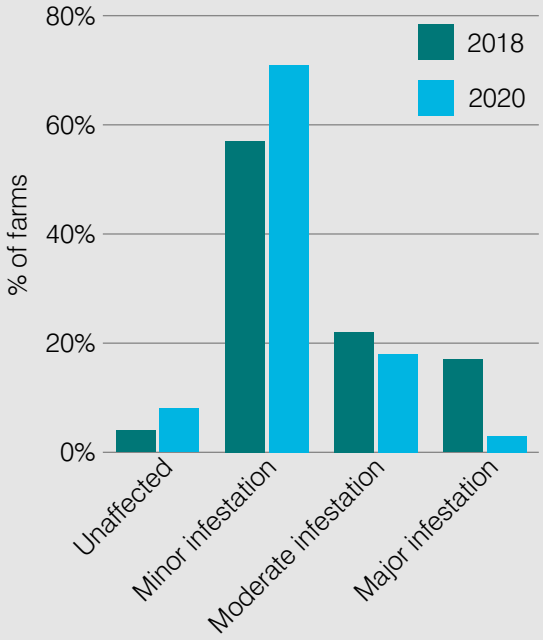
The ISC had over 3.4 million visits in 2020, over double the number in 2017. Users came from all countries in the world (except the Holy See). A study was conducted using a variety of methods to assess what the ISC is used for, and what makes it so popular. An online survey using SurveyMonkey was sent to members of WhatsApp groups for the Entomological Society of Kenya and the Kenya Fall Armyworm Taskforce, to examine ISC use in the context of the fall armyworm invasion. A public HotJar survey was also offered on the ISC website, and both surveys were followed up with emails and interviews. The assessments found that the ISC is highly valued as the information is current, reliable and open access. Users reported visiting the ISC for information to support research, identification of species, policy development, awareness raising, management and risk assessment. Other users also reported visiting the ISC to source information for habitat surveys, biosecurity work, regulatory action and agronomic advice. The fall armyworm datasheet and species portal were the most visited in the period 2018–2020, providing information on identification, management and distribution. Usage of these pages increased in certain regions as fall armyworm spread. For example, from May 2018, when the species was first reported in Asia, there was a dramatic increase in visits to armyworm pages from the region. Similarly, pages on desert locust in Kenya, invasive cabbage pests in Jamaica, and invasive fruit flies in South Africa were all used more heavily at times of particular need.

Independently of the Action on Invasives programme, a published study compared the ISC with three other public databases (**https://doi.org/10.1016/j.gecco.2020.e01332**), for 49 invasives of concern to the European Union. The ISC ranked significantly higher than the other databases overall, and highest for the individual topics of species identification, impacts, control options, and citations.

Changes in farmers' management of fall armyworm

In 2018, a household survey in Ghana recorded how farmers were coping with fall armyworm. Two years later 370 of the same farmers were surveyed again, to see how the problem and their response had changed.

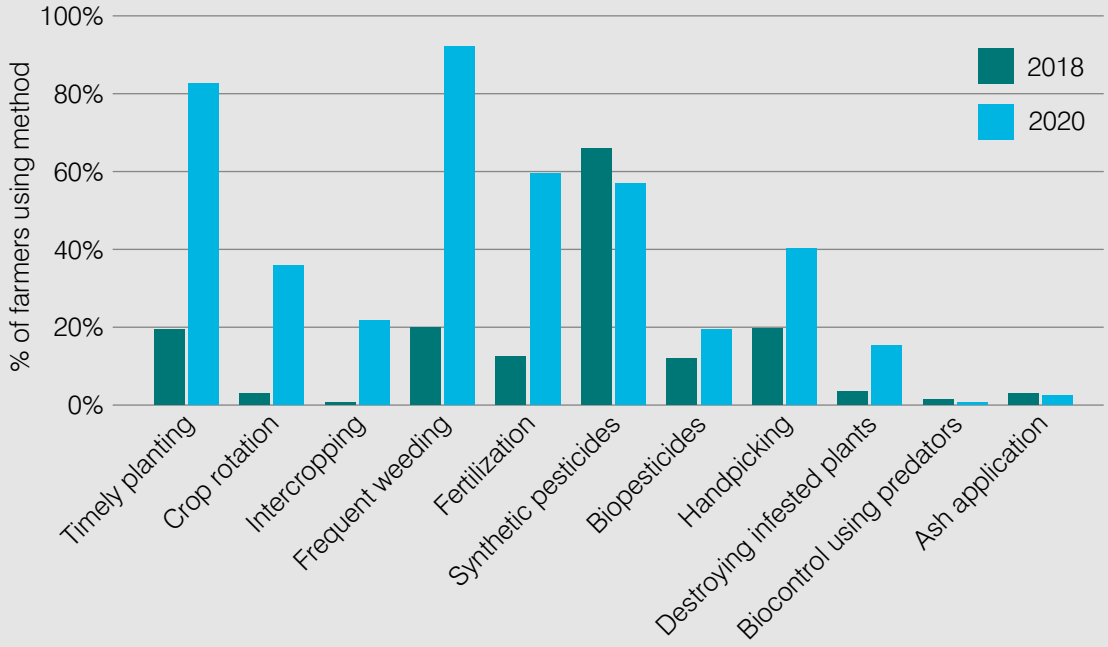
Fall armyworm still a problem



Reduced use of pesticides

	Average no. of pesticide sprays per season	Amount spent on pesticides (GHC/hectare)
2018	2.45	113.1
2020	1.52	49.6

Increased use of cultural practices



The Fall Armyworm Research Collaboration Portal was launched in June 2020, and now has over 600 registered users (from 85 countries) sharing research information, updates and questions with visitors from over 160 countries. In a short survey of the portal users, 82% of people reported that the portal was helpful in their work, allowing them to keep up to date with fall armyworm news and research, connect with people from different countries, and gather insights from other areas on fall armyworm management that can be applied in their local context. Several users reported making new connections through the portal that had led to project proposals, and many obtained answers to questions posted on the portal. However, there remain several barriers to users sharing their research – and in particular research data.

Readership details of all programme publications and outputs have not been compiled, but the paper summarizing the 2017 evidence note on fall armyworm continues to be frequently cited, and on ResearchGate has now been read over 14,000 times, while the evidence note on tomato pinworm has been read over 4,000 times.

Number of countries/regions that are more responsive to invasive species threats

The methodology earlier developed and used in Kenya for assessing the overall responsiveness of a country to invasive species was based on three steps: a desk review, key informant interviews, and a stakeholder workshop. In 2020 this method was adapted for use in Bangladesh and Zambia, with additional interviews but no workshop. The findings in Bangladesh show that there are a broad range of actors present in the invasive species system, with high levels of technical expertise. This was exemplified by the rapid establishment of a national taskforce when fall armyworm was first detected in the country in 2018. However, although existing policies and regulations that govern the way invasive species management is delivered are adequate, they are not always well implemented, and the links between various actors and organizations need strengthening. Establishing a central co-ordinating body that would bring together the various actors in a cross-sectoral and multi-species approach to IAS management was a high priority amongst key informants. Similarly, in Zambia there are many strengths, including a broad range of actors collaborating to address particular invasive species, as well as strong community involvement. Challenges to the system include inadequate co-ordination/communication, a fragmented sector-based approach to managing invasive species, some institutional/legislative gaps, and limited monitoring and evaluation. Following the assessment, Zambia is now formally establishing a national co-ordination mechanism for invasive species management. As noted previously, as well as identifying opportunities for strengthening the system, this assessment provides a baseline against which progress can be evaluated in the future.

In 2017 Action on Invasives supported the development of a national action plan for fall armyworm in Ghana, and in 2020 a study was conducted to evaluate different stakeholders' experiences of its implementation and impact. The plan focused on four key elements – collaboration, awareness, surveillance, and research and management – with a government-led task force overseeing and co-ordinating implementation. The outcomes were categorized into the same four areas plus a fifth area on policy. Outcome harvesting, a Sprockler inquiry, and key informant interviews were used in the evaluation, with responses obtained from 130 stakeholders. The evaluation showed that while the initial response was considered slow, once the response had been planned and implemented, there was good stakeholder collaboration at various levels, leading to increased public awareness of fall armyworm and management practices, supported by the household survey data reported above. R&D on low-risk management options was initiated, and the government promoted biorational plant protection products. Additionally, within the ambit of responding to fall armyworm, significant contributions have been made to policy and practice on how threats from invasive species can be managed more effectively in future. Challenges identified in the evaluation included the slow initial response, a lack of funds and limitations within the agricultural extension system. Proposed actions to improve future preparedness included the establishment of a standing taskforce to address new invasives (already initiated); the establishment of an emergency fund to enable quick response; improved monitoring and surveillance; strengthened capacity in PRA; and the development of a strategic communication plan. These areas are addressed in the NISSAP, implementation of which has commenced.

Experience of the fall armyworm response

In 2017, Action on Invasives supported stakeholders to develop a national action plan for fall armyworm in Ghana. Three years on, what have been the experiences of stakeholders?

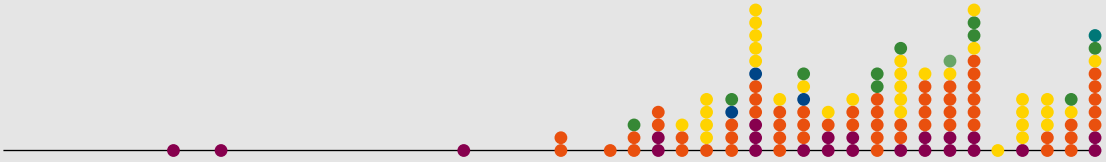
Group

- Central government civil servant
- Local government civil servant
- NGO representative
- Farmer
- Chief or local opinion leader
- Input dealer
- Researcher
- Journalist
- Development partner

Timeliness of information provision

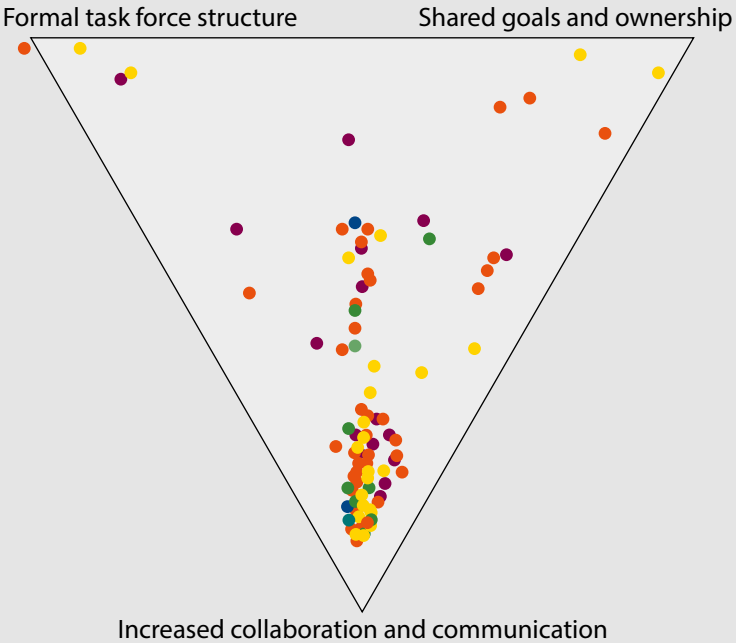
Information was much too late — Information arrived in good time

Stakeholder collaboration



Has become a lot worse — Has strengthened enormously

Success factors



Publications

Programme-funded (published)

Agboyi LK, Goergen G, Beseh P, **Mensah SA**, **Clottey VA**, Glikpo R, **Buddie A**, **Cafà G**, **Offord L**, **Day R**, **Rwomushana I** and **Kenis M** (2020). "Parasitoid complex of fall armyworm, *Spodoptera frugiperda*, in Ghana and Benin". Insects 11 No. 2: 68, 15 pp. **https://doi.org/10.3390/insects11020068**

Ali K, **Rehman A**, **Khan K** and **Weyl P** (2020). "Comparative efficacy of common broad leaf herbicides against an invasive weed*:* *Parthenium hysterophorus* L.". Agricultural Sciences 11 No. 7, 617–626. **https://doi.org/10.4236/as.2020.117039**

Babendreier D, **Agboyi LK**, Beseh P, Osae M, Nboyine J, Ofori SEK, Frimpong JO, **Clottey VA** and **Kenis, M** (2020). "The efficacy of alternative, environmentally friendly plant protection measures for control of fall armyworm, *Spodoptera frugiperda*, in maize". Insects 11 No. 4, 240, 21 pp. **https://doi.org/10.3390/insects11040240**

Baldissera G, Blümel S, Lopian R, Teulon D, Bloem S, Martínez CG, Montoya CB, Morales CRU, Dharmapuri S, Timote V, Horn N, Chouibani M, M'Ella JGM, Herrer V, Castinel A, Goletsos C, Moeller C, Naumann I, Stancanelli G, Bronzwaer S, Tramontini S, MacDonald P, Matheson L, Anthoine G, De Jonghe K, Schenk M, Steinmöller S, Rodriguez E, Cruz ML, Luck J, Fraser G, Brunel S, Montuori M, Fedchock C, Steel E, Pennington HG, **Day R**, Rossi JP and Xia J (2020). "Science diplomacy for plant health". Nature Plants , 6, 902–905. **https://doi.org/10.1038/s41477-020-0744-x**

Bateman M, **Day RD**, **Rwomushana I**, Subramanian S, Wilson K, **Babendreier D**, **Luke B** and **Edgington S** (2020). "Updated assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa". Journal of Applied Entomology 00, 1–10. **https://doi.org/10.1111/jen.12856**

Constantine KL, **Kansiime MK**, **Mugambi I**, **Nunda W**, **Chacha D**, **Rware H**, **Makale F**, **Mulema J**, **Lamontagne-Godwin J**, **Williams F**, **Edgington S** and **Day R** (2020). "Why don't smallholder farmers in Kenya use more biopesticides?". Pest Management Science 76 No. 11, 3615–3625. **https://doi.org/10.1002/ps.5896**

Constantine KL, **Murphy ST** and **Pratt CF** (2021). "The interaction between pests, mixed-maize crop production and food security: a case study of smallholder farmers in Mwea West, Kenya". Cogent Food & Agriculture, 6 No. 1, 1–18. **https://doi.org/10.1080/23311932.2020.1857099**

Durocher-Granger L, Mfune T, Musesha M, **Lowry A**, **Reynolds K**, **Buddie A**, **Cafà G**, **Offord L**, Chipabika G, Dicke M, and **Kenis M** (2020). "Factors influencing the occurrence of fall armyworm parasitoids in Zambia". Journal of Pest Science. **https://doi.org/10.1007/s10340-020-01320-9**

Fallet P, Machado RAR, **Toepfer S**, Ye W, **Kajuga J**, Waithira B, Bazagwira D, and Turlings TCJ (2020). "A Rwandan survey of entomopathogenic nematodes that can potentially be used to control the fall armyworm". Microbial and Nematode Control of Invertebrate Pests. IOBC-WPRS Bulletin 150, 87–90. **https://www.researchgate.net/publication/341553716**

Finch EA, **Beale T**, Chellappan M, Goergen G, Gadratagi BG, Khan MAM, **Rehman A**, **Rwomushana I**, Sarma AK, Wyckhuys KAG and Kriticos DJ (2020). "The potential global distribution of the papaya mealybug, *Paracoccus marginatus*, a polyphagous pest". Pest Management Science 77 No. 3, 1361–1370. **https://doi.org/10.1002/ps.6151**

Iqbal IM, **Ali K**, **Evans HC**, **Rehman A**, **Seier MK**, Shabbir A, and **Weyl P** (2020). "The first record of *Puccinia abrupta* var. *partheniicola*, on *Parthenium hysterophorus* an invasive alien plant species in Pakistan". BioInvasions Records 9 No. 1, 1–7. **https://doi.org/10.3391/bir.2020.9.1.01**

Kansiime MK, **Rwomushana I, Mugambi I**, **Makale F**, **Lamontagne-Godwin J**, **Chacha D**, Kibwage P, Oluyali J, and **Day R** (2020). "Crop losses and economic impact associated with papaya mealybug (*Paracoccus marginatus*) infestation in Kenya". International Journal of Pest Management. **https://doi.org/10.1 4.2020.1861363**

Tambo JA, **Day R**, **Lamontagne-Godwin J**, **Silvestri S**, Beseh PK, **Oppong-Mensah B**, **Phiri NA** and Matimelo M (2020). "Tackling fall armyworm (*Spodoptera frugiperda*) outbreak in Africa: an analysis of farmers' control actions". International Journal of Pest Management 66 No. 4, 298–310. **https://doi.org/10.1080/09670874.2019.1646942**

Tambo JA, **Kansiime MK**, **Mugambi I**, **Rwomushana I**, **Kenis M**, **Day RK** and **Lamontagne-Godwin J** (2020). "Understanding smallholders' responses to fall armyworm (*Spodoptera frugiperda*) invasion: Evidence from five African countries". Science of the Total Environment 740, 140015, 11 pp. **https://doi.org/10.1016/j.scitotenv.2020.140015**

Witt ABR, Floyd KS, **Nunda W**, **Beal, T**, Shanungu G, and Kriticos DJ (2020). "*Mimosa pigra* in eastern and southern Africa: Distribution and socio-ecological impacts". Austral Ecology 45 No. 6, 788–799. **https://doi.org/10.1111/aec.12895**

Programme-funded (accepted for publication)

Buddie AG, **Rwomushana I**, **Offord LC**, Kibet S , **Makale F**, **Djeddour D**, **Cafa G**, Vincent KK, Muvea AM, **Chacha D**, and **Day RK** (2021). "First report of the invasive apple snail, *Pomacea canaliculata* in Kenya". CABI Agriculture and Bioscience

Tambo J, **Kansiime M**, **Rwomushana I**, **Mugambi M**, **Nunda W**, **Banda CM**, Nyamutukwa S, **Makale F** and **Day R** (2021) "Impact of fall armyworm invasion on household income and food security in Zimbabwe". Food and Energy Security

Toepfer S, **Fallet P**, Kajuga J, Bazagwira D, Mukundwa IP, Szalai M, Turlings TCJ (2021). "Streamlining leaf damage rating scales for the fall armyworm in maize". Journal of Pest Science

Weyl P, **Ali K**, **González-Moreno P**, **ul Haq E**, **Khan K**, Khan SA, Khan MH, **Stewart J**, **Godwin J**, **Rehman A**, **Sultan A** (2021). "The biological control of *Parthenium hysterophorus* L. in Pakistan: status quo and future prospects". Management of Biological Invasions 12 (in press)

Programme-funded (submitted for publication)

Agboyi LK, Layode F, Fening K, Beseh P, **Babendreier D**, and Kenis M (2021). "Assessing the potential of inoculative field release of *Telenomus remus* to control the fall armyworm, *Spodoptera frugiperda* in real field condition in Ghana". Insects

Agboyi LK, Nboyine J, **Babendreier D**, Beseh P, and **Kenis M** (2021). "Effect of pesticides and biopesticides on parasitism of *Spodoptera frugiperda* in Ghana". Environmental Health Perspectives

Allen T, **Kenis M**, and Norgrove L (2021). "*Eiphosoma laphygmae*, a classical solution for the biocontrol of the fall armyworm, *Spodoptera frugiperda*?". Journal of Plant Diseases and Protection

Eschen R, **Beale T**, **Bonnin JM**, **Constantine KL**, **Duah S**, **Finch EA**, **Makale F**, **Nunda W**, **Ogunmodede A**, **Pratt CF**, **Thompson E**, **Williams F**, **Witt A**, and **Taylor B** (2021). "The economic cost of invasive alien species to African crop and livestock production". CABI Agriculture and Bioscience

Makale F, **Mugambi I**, **Kansiime MK**, Yuka I, Lechina BS, and **Rwomushana I** (2021). "Fall armyworm in Botswana: Impacts, farmer management practices and implications for sustainable pest management". Pest Management Science

Rware H, Kansiime M, Banda CM, Mugambi I, Onyango D, Godwin J, Davis T and Tambo JA. (2021). "Is radio an effective outreach method for delivering actionable information for responding to emerging pest threats? A Case study of Fall armyworm campaign in Zambia". CABI Agriculture and Bioscience

Rwomushana I, Landers I, Jepson P, Murray K, **Kansiime MK**, **Chacha D**, and **Day RK** (2021). "Diversity of pesticides sold by agrodealers for the management of fall armyworm (*Spodoptera frugiperda*) in Kenya". CABI Agriculture and Bioscience

Weyl P, **Rehman A**, **Ali K** (2021). "*Listronotus setosipennis*, a suitable biological control agent against *Parthenium hysterophorus* in Pakistan". Insects

Other papers relevant to Action on Invasives

Fiaboe KR, Agboka K, **Agboyi LK**, Koffi D, Ofoe R, Kpadonou GE, Agnamba AO, Assogba K, Adjevi MKA, Zanou KT, Fening OK (2020). "First report and distribution of the South American tomato pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera:Gelechiidae) in Togo". Phytoparasitica. **https://doi.org/10.1007/s12600-020-00841-4**

Linders TEW, Bekele K, **Schaffner U**, Allan E, Alamirew T, Choge SK, Eckert S, Haji J, Muturi G, Mbaabu, PR, Shiferaw and **Eschen R** (2020). "The impact of invasive species on social-ecological systems: Relating supply and use of selected provisioning ecosystem services". Ecosystem Services 41, 101055, 14 pp. **https://doi.org/10.1016/j.ecoser.2019.101055**

Niassy S, Ekesi S, **Migiro L** and **Otieno W** (2020). "Introduction: An overview of the impacts of invasive insect species on agriculture". In: Niassy, S., Ekesi, S., Migiro, L., Otieno, W. (eds) *Sustainable Management of Invasive Pests in Africa*. Sustainability in Plant and Crop Protection, vol 14. Springer, Cham, Switzerland, pp. 1–9. **https://doi.org/10.1007/978-3-030-41083-4_1**

Overton, K, Maino, J, **Day, R**, Umina, P, Bett, B, Carnovale, D, Ekesi, S, Meagher, R and Reynolds, O. (2021). "Global crop impacts, yield losses and action thresholds for fall armyworm (*Spodoptera frugiperda*): a review". Crop Protection (in press)

Reports (non-peer reviewed)

Djeddour D, **Pratt C**, **Makale F**, **and Rwomushana I** (2021). "The apple snail *Pomacea canaliculata*: invasiveness and potential economic impacts for East Africa". CABI Working Paper

Kansiime, M.K., Beseh, P, Hevi, W., Lamontagne-Godwin, J., Clottey, V.A., Rwomushana, I., Day, R., Rware, H., Aboagye, E. and Williams F. (2020). "Implementation of fall armyworm management plan in Ghana: outcomes and lessons for invasives species management". CABI Study Brief 34: Learning. DOI **https://dx.doi.org/10.1079/CABICOMM-62-8138**

Luke B (2021). "Strategies to improve uptake of bioprotection products in desert locust control". CABI Working Paper.

Weyl P, **Ali K**, **Godwin J**, **Beale T**, **Khan K**, **Rehman A**, **Safdar U,** Breton R, and Fenell J (2020). "Parthenium weed research in Pakistan: An update". International Parthenium News, No 15, 8–10. **https://apwss.org/apwss-ipawn.htm**

Annex 1: Associated projects

Drones for desert locust control in East Africa/FCDO

CABI and Astral-Aerial have partnered to pilot the use of unmanned aerial vehicles to control the desert locust. Funded by the UK's FCDO, the pilot project is evaluating the benefits and efficiency of using drone technology as a complementary spraying method to manage desert locusts, particularly for prevention through targeting hoppers in their breeding areas. The outcome from the project will be a set of standard operating procedures for the safe and efficient use of drones in desert locust control operations.

IPM against the invasive fall armyworm in Malaysia

This nationally funded project led by the Malaysian Agricultural Research and Development Institute (MARDI), with CABI as a partner, has four objectives: (1) conduct a baseline and scoping analysis of the current situation of fall armyworm infestation; (2) conduct laboratory tests on bio-based and chemical interventions; (3) formulate an interim IPM programme and evaluate it in farmers' fields; and (4) provide recommendations for sustainable scaling up of IPM, including awareness and capacity development.

Characterization of fall armyworm populations in South-East Asia and Northern Australia

CABI is one of several partners working on this project with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australia, which is co-funded by the Australian Grains Research and Development Corporation (GRDC). Sequencing studies are being conducted in Australia with samples from different areas, and at the same time laboratory bioassays of the different populations are being conducted to characterize resistance status. CABI is partnering with MARDI to do work in Malaysia.

Sustainable management of fall armyworm in Botswana

The fall armyworm invasion in Botswana posed a threat to food and nutrition security for vulnerable farming communities and households. This FAO project aimed to mitigate the negative impacts of fall armyworm, and promoted the use of IPM, while supporting the development of a national strategy for the sustainable management of fall armyworm in Botswana. CABI was contracted to implement a survey, and training and awareness activities.

Potential fall armyworm invasion in Switzerland

This project is funded by the Swiss Federal Office of Agriculture, and is conducted in close collaboration with the five partners of an EU Euphresco project on the potential introduction, spread, damage and control of fall armyworm in Europe. The project started in 2019 and ends in late 2021. So far, CABI has produced a report on management methods that are appropriate for temperate climates where the moth is a temporary migrant, and a paper is in preparation. With Euphresco partners, the project is also developing climate models for Europe. It is also assessing potential biocontrol methods available in Switzerland, with a special focus on egg parasitoids of the genus *Trichogramma*.

Classical biological control against fall armyworm

The Swiss Agency for Development and Cooperation is supporting the establishment of a joint MARA China – CABI European Laboratory in Delémont, Switzerland. Under this project work is being conducted on classical biological control of fall armyworm: in particular, surveys and studies on parasitoids of the pest in its area of origin in Central and South America. Surveys are being carried out in collaboration with national partners in Bolivia, Nicaragua, Peru and Brazil.

Aflatoxin control in Pakistan

The US Department of Agriculture (USDA) has pioneered the biological control of aflatoxins using atoxigenic strains of *Aspergillus*, and the technology is being transferred to Pakistan, trademarked as AflaPakTM. CABI's role in the project is to build the capacity of the national agricultural system, including farmers, governments and stakeholders, to regulate and use the product. Field trials with private and public partners confirmed the efficacy of the product, and a registration dossier has been submitted to the Department of Plant Protection (DPP). The current regulatory system was designed for synthetic pesticides, so US partners have supported the drafting of a regulatory protocol that is appropriate for the product. However, the protocol could also serve to facilitate the registration of biopesticides for fall armyworm and other invasives species (none are currently registered in Pakistan).

Using remote sensing for mapping parthenium in Pakistan

This project was led by the University of Manchester with funding from the UK Science and Technology Facilities Council and aimed to develop methods for mapping and monitoring the distribution of parthenium, strengthen capacity to utilize remote-sensing technologies and satellite data, and create and disseminate parthenium distribution data for policy-makers' decision-making in agriculture, livestock and human health. Ground truth data were collected from over 4,000 sites and algorithms were developed to use those data to map national distribution using Sentinel-2 (10m) imagery. A low-cost quadcopter camera was also developed to collect information in a given area on the actual distribution of parthenium.

Agriculture and biodiversity: addressing scale insect threats in Kenya

This Darwin Initiative project was jointly implemented by the Natural History Museum UK, five national organizations, and CABI. It aimed to increase the capacity of stakeholders to identify scale insects taxonomically, as well as to manage them in the field. Over 60 species in Kenya are potentially damaging to agricultural production, and several of these are invasive species, such as papaya mealybug, which afforded opportunities for synergies with Action on Invasives.

Fall armyworm in India

This project, funded by the Government of India and CABI's Development Fund, is being undertaken with the Indian Council of Agricultural Research's National Bureau of Agricultural Insect Resources, including both research and awareness raising on IPM technologies for fall armyworm. Molecular characterization of fall armyworm from different parts of India has been undertaken. Surveys for native natural enemies found *Telenomus remus* and several *Trichogramma* species attacking the eggs. IPM trials are being conducted with a range of non-chemical methods.

USDA-APHIS Caribbean invasive plants datasheets

This project, funded by USDA-APHIS, involved working with a team of experts to develop detailed datasheets on invasive plants now found in the Caribbean. Under this project, a total of 152 datasheets were prepared and published in the ISC in 2020.

ITAP plant pathogen datasheets

Funded by USDA-APHIS, the Federal Interagency Committee on Invasive Terrestrial Animals and Pathogens Subcommittee on Plant Pathogens prioritized plant pathogens that could pose a risk to the US. Where there were gaps in the coverage of the ISC for these pathogens, CABI commissioned and published new detailed datasheets on those species. In total, 33 new datasheets were developed and made available on the ISC.

The Global Burden of Crop Loss

The GBCL, initially funded by the Bill and Melinda Gates Foundation, is an initiative to capture and measure the global trends in crop loss and the impacts of crop pests and diseases (native and non-native) so that the allocation of resources and the prioritization of efforts can be matched to the need. The GBCL will be a system that collects, validates, analyses and disseminates data on crop losses. Since 2019 the GBCL consortium has evaluated relevant methods and datasets, and has developed a theoretical framework. In October 2020 a week-long series of webinar workshops enabled a range of stakeholders to discuss key questions, and clearly identified the need for an economic metric of impact. Subsequent stages over the next five years have been outlined.

Preparedness and management for fall armyworm in Australia

CABI was part of a team led by Cesar Australia commissioned by the GRDC to develop a research, development and extension gap analysis. The analysis covered preparedness, potential economic impacts, geographic range, affected crops, pest biology, and management implications, including resistance profiles and similarity to existing endemic pests. Management options (chemical, biological, genetic pre-breeding, cultural) were reviewed for Australian plant industries, with a focus on grains. The analysis also provided the basis for an industry continuity plan (**www.planthealthaustralia.com.au/fall-armyworm/**).

Response to enhance technical capacity for monitoring and management of fall armyworm in Bangladesh

An FAO project aimed to survey and collect data on the fall armyworm infestation, build capacity to use the FAO monitoring app (FAMEWS), and promote awareness among the affected communities on effective management. CABI was commissioned to provide support in the awareness raising, in producing and distributing information materials, and in providing training on the use of the monitoring app. In a related FAO project on e-surveillance, 10 solar-powered automated pheromone traps were deployed to provide weekly assessments of the pest population. Partners in this project were the Department of Agricultural Extension, research institutes and a university.

Annex 2: Conferences/workshop attendance

A number of meetings, workshops and conferences were attended during the year, all of them virtual. The following list includes those at which a presentation was made.

- International Seminar on Transboundary pest management, "CABI initiatives to manage transboundary pests", Tamil Nadu Agricultural University, Coimbatore, 4–5 March 2020.
- Healthier plants with the help of Biologicals? "How enabling policy can facilitate uptake of biologicals: The EAC harmonization process", Alnarp, Sweden, 19 May 2020.
- Pesticides and biopesticides in fall armyworm control: Protecting Health of Plants, People and the Planet, "Field experiences with pesticides and biopesticides for fall armyworm management: The case of Kenya and South Sudan", FAO, Rome, Italy, 11 June, 2020.
- ESOF2020, "Invasive species and climate change: Africa's 21st century challenge", Trieste, Italy, 2–6 September 2020.
- ASEAN/GrowAsia Webinar Series on Biocontrol Approaches for Fall Armyworm, "Prospects for the classical biological control of *Spodoptera frugiperda* in Asia and Africa using parasitoids from America", 10 September 2020.
- Journée d'Automne SSP 2020, "Les ravageurs envahissants et les risques pour la sécurité alimentaire", Liebefeld, Switzerland, 2 October 2020.
- CABI side event at the World Food Prize/2020 International Borlaug, Des Moines, Iowa, USA, "A plague during a pandemic: how to increase resilience against the desert locust outbreak", 12–16 October 2020.
- FAO and Thai Education Foundation Regional Training Workshop for Farmer Field School facilitators on sustainable management of Fall Armyworm: IPM, Biocontrol and Farmer Field Schools, "Summary of Grow Asia/CABI Webinar Series on fall armyworm Biocontrol", 29 October 2020.
- ASEAN/GrowAsia fall armyworm biocontrol technical workshop, "Field collection and identification of fall armyworm parasitoids and predators", 17 December 2020.

Annex 3: 2020 milestones

The table below summarizes achievements for the planned milestones, and how COVID-19 affected activities within a milestone.

Status

Milestone activities were revised during the year

● – Completed as per revised plan

■ – Minor variance from revised plan

▲ – Major variance from revised plan

COVID change

Summary of how activities and associated budgets were adjusted from the original plans:

L: Little or no change to planned activities

A: Adjusted activities, but within the same/similar budget

R: Reduced or modified activities, with a reduced budget

I: Increased or expanded activities, with an increased budget

N: New milestone. Milestone A was added to reflect new activities. Milestone B was erroneously omitted previously

Description of change

Brief summary of changes as a result of COVID-19

Achievement

As in previous reports, a summary of what was achieved under the milestone

#	Stakeholder Engagement	Status	COVID change	Description of change	Achievement
1	Programme initiated in seven countries (cumulative)	■	R	Overall programme budget for the year reduced. Work in Rwanda and Burkina Faso limited	Some activities implemented in all seven countries: Bangladesh, Burkina Faso, Ghana, Kenya, Pakistan, Rwanda and Zambia
2	National response plan developed for two prioritized invasive species in Africa and one species in Asia	●	A	Surveillance for risks prioritized by horizon scanning was delayed in Ghana and Pakistan, so selection of species for response plans was delayed. Instead, responses to desert locust and apple snail in Kenya were supported	National desert locust strategy for Kenya developed. Molecular identification confirmed arrival of apple snail in Kenya; delimiting survey undertaken; apple snail evidence note drafted
3	National technical working group for invasive species institutionalized in two countries in Africa	●	L		Technical working groups on invasive species in Ghana and Kenya formed and meetings held
4	Processes for streamlining regulations for registration of lower-risk products facilitated in Africa and Asia	■	R	No opportunity to promote or test the harmonized biopesticide guidelines in East Africa. Draft biopesticide registration protocol in Pakistan not yet approved so promotion not possible	Guidelines for import and release of biological control agents and other beneficial organisms developed and adopted in Ghana. East African Community harmonized guidelines printed and disseminated to Member States.
5	Programme monitored in six countries as an integral part of Plantwise planning and implementation	■	R	Travel to facilitate and monitor implementation in the countries not possible	Some interactions and meetings possible where CABI has offices in country
6	Partnerships strengthened at international, regional and national levels for the management of invasive species	●	R	Almost all regional and international meetings became virtual, reducing the need for travel	Desk study on opportunities to link national plans for climate change adaptation and invasive species management conducted. Remote participation in virtual national, regional and international meetings on fall armyworm and invasive species. Contributions to regional and international programmes on fall armyworm

7	National invasive species strategy and action plan implemented in one country and opportunities for developing a NISSAP in one additional country initiated	■	A	Stakeholder meeting conducted virtually rather than face-to-face	Invasive species strategy for Pakistan developed without face-to-face meetings. Ghana implementation commenced but delayed
8	One continental invasive strategy finalized and disseminated widely among relevant partners, and implementation assessed in two countries	●	R	Planned validation meeting and implementation of Africa strategy not possible due to travel restrictions	Africa Continental Invasives Species Strategy published with translations of summary into Arabic, French, Portuguese, Spanish and Swahili. Promoted through online communications and virtual meetings only
9	National invasive species system response capacity assessed in two countries	●	R	Stakeholder workshops not possible. Local consultants conducted additional key informant interviews	National invasive species system assessments conducted for Bangladesh and Zambia
A	Policy-makers/decision-makers informed of options for reducing invasive species impacts using lower-risk control methods and products	●	I/N	New activities to respond to new invasions	Videos and evidence note on Green MuscleTM biopesticide for locusts produced
B	Methods for monitoring the cost of invasive species developed and applied, providing information for policy-makers and decision-makers	●	A/N	CABI's International Year of Plant Health conference in Netherlands cancelled, so presentation of study on costs of invasive species in Africa not made. Collaboration with University of Minnesota added to programme	Study on costs of invasive species in Africa completed and submitted for publication Global multi-peril risk analysis for maize commenced within the GBCL initiative Economic impacts and management options for citrus HLB in East Africa estimated in evidence note

#	Best Practice Solutions	Status	COVID change	Description of change	Achievement
10	Invasive risk assessments and risk prioritization implemented in at least two countries	■	R	Risk prioritization activity in Pakistan conducted late in the year, as a training exercise on one crop (tomato)	Prioritization in Ghana completed; the training activity commenced in Pakistan will be completed in 2021
11	Risk management (prevention and rapid response) procedures researched and developed in at least two countries for priority invasive species	■	A	Delays as field trips were not possible during various periods, and the procedures had to be adapted	Surveys and surveillance for several invasive plant pests were carried out following prioritization exercises in Ghana and Kenya. Early warning and rapid response programme against *Prosopis* in Kenya initiated
12	Biological control methods against parthenium weed researched, developed and validated for application in one country	I	L		Host range tests for *Listronotus setosipennis* in Pakistan completed; draft dossier for release prepared. *Zygogramma bicolorata* redistributed. National surveys for parthenium winter rust carried out
13	Biocontrol and other IPM-compatible technologies against fall armyworm researched, developed and validated to support delivery at scale in five countries in Asia and Africa	■	A	Some field work delayed for completion in 2021, but much continued as planned	Ghana: Production and release trial of *Telenomus*; conservation biocontrol tested through intercropping and biopesticide use Zambia: Conservation biocontrol tested through intercropping and date of planting changes; natural enemy surveys Kenya: Pherogen (pheromone) and Fawligen (virus biopesticide) registered following earlier trials by CABI Bangladesh: Production and release of augmentative biocontrol (*Trichogramma* and *Bracon*); natural enemy surveys Rwanda: Field testing of entomopathogenic nematodes Burkina Faso: Testing of biopesticides and natural enemy surveys Pakistan: Natural enemy surveys; rearing of native and exotic parasitoids for biological control Switzerland: Laboratory risk assessments of *Eiphosoma laphygmae*; shipped to quarantine in Pakistan and Benin

14	Biological control and other IPM-compatible technologies researched, developed and validated for at least two additional invasive plant pests to support delivery at scale in three countries in Asia and Africa	■	A	Importation of *Acerophagus papayae* to Kenya for papaya mealybug biological control delayed. Biological control of tomato leaf miner progressed more slowly than planned	Papaya mealybug parasitoid *Acerophagus papaya* imported from Ghana to Kenya and a culture established in quarantine for field releases in 2021 Parasitoids and predators of tomato pinworm studied in Ghana and Zambia in the lab and field; virus-based product tested in Ghana. IPM of pinworm studied in Kenya in trials with farmers. Adequate information is now available to implement an IPM system for the pest in sub-Saharan Africa
15	Invasive species management research capacity increased in at least five countries	●	A	Most supervision of students and young scientists had to be conducted remotely	In Ghana and Pakistan, national researchers were trained on invasive pest prioritization processes. MSc and PhD students and young staff were supervised on various aspects of invasive species management in Ghana (fall armyworm and tomato pinworm); Zambia (tomato pinworm); Rwanda (fall armyworm); Burkina Faso (fall armyworm); Kenya (fall armyworm, papaya mealybug, Prosopis); and Pakistan (parthenium, fall armyworm)

#	Community Action	Status	COVID change	Description of change	Achievement
16	5 million (cumulative) rural households reached with new knowledge on climate-smart pest and invasive species management; >500,000 receiving and acting on CABI info on parthenium and fall armyworm and control options	●	L		Campaigns implemented on fall armyworm (Ghana, Zambia, Pakistan, Bangladesh); tomato pinworm (Ghana); papaya mealybug (Kenya); Parthenium (Pakistan). >930,000 reached
17	Baseline survey and socioeconomic impacts of one invasive species documented and disseminated	●	L		Survey of 1,435 farmers in Ghana (including 370 previously surveyed in 2018) to evaluate impacts and management of fall armyworm. Increased use of agronomic practices and reduced pesticide in line with recommendations
18	Two technical briefs on key invasives developed and popularized in local language in two countries	●	A	Workshop held virtually in Pakistan	Two briefs developed: on papaya mealybug in Kenya, and on tomato pinworm in Pakistan (used to produce materials in Urdu)
19	Five community area-wide management plans for control of fall armyworm implemented, utilizing at least two new best practices in Africa and Asia	●	R	Demonstration of low-risk options for management of fall armyworm in two counties in Kenya was dropped	Seven communities (four in Ghana and three in Kenya) engaged in area-wide management for fall armyworm using biological and low-risk controls. 200,000 *Telenomus remus* released in the four communities in Ghana. Gendered technology assessment included in Kenya activities. In Pakistan, communities were engaged indirectly on management of fall armyworm through partnership with the PRSP. A total of 96 community organizations engaged in monitoring and applying lower-risk chemicals
20	At least two evaluations of communication and community engagement campaigns in two countries	■	L	Zambia assessment delayed	External evaluation of 2019 national mass extension campaign on parthenium conducted in Pakistan. Evaluation of Zambia fall armyworm SMS campaign undertaken in partnership with Plantwise and PRISE. Data analysis is underway
21	Campaign for policy engagement on parthenium in one country initiated		R	Cancelled	

#	Knowledge and Data	Status	COVID change	Description of change	Achievement
22	Invasives PRA tool enhanced and used by quarantine/plant protection staff in 35 countries (cumulative); evidence to demonstrate impact collected and disseminated	●	I	Additional development work on the PRA tool. User support, collection of feedback on the tool, and expert consultation on technical solutions was conducted remotely	User feedback collected, expert consultations conducted. New features added: online and offline PRA sharing, rapid assessment, regulated pest lists, automation for several PRA sections, self-guided help
23	Open source collaborative platform for fall armyworm evidence and actions developed	●	A	Promotion of the Research Collaboration Portal was done entirely remotely	Fall Armyworm Research Collaboration Portal released in June, guided by steering committee and user input. Over 600 registered users and 16,000 visits
24	Upgraded invasives knowledge platform launched with improved data visualization; at least 2.5 million visits	●	L		Over 3.4 million visits to the ISC in 2020. Improved maps with better display of distribution data, filters and customizable legends. Improved user experience when on homepage and when navigating in datasheets
25	ISC content and data maintained and updated, including 600 updated datasheets and 10 new datasheets published; one new species portal added	●	L		Ten new datasheets were added and over 2,500 were updated with new data. Over 100 new management factsheets and reports added to the compendium. New species portal added for the apple snail *Pomacea canaliculata*
26	Refine distribution database; integration of at least three new datasets feeding decision support tools	●	L		Improvements made to distribution database to increase automation of bulk uploads of datasets. Three datasets uploaded and feeding decision support tools
27	Promote and expand information management system with data from CABI projects and external data in line with Action on Invasives data strategy	●	L		Improvements made to CABI data management site (CKAN) in line with data best practices. New datasets added and assigned DOIs. Two virtual workshops conducted to build capacity in use of ODK and CKAN in other CABI projects
28	30 papers (cumulative) published in academic literature	●	I	Additional time allocated to paper writing	15 papers published in 2020 (cumulative 36); four others already accepted for publication; eight more submitted, awaiting decision

#	Fund Raising and Market Development	Status	COVID change	Description of change	Achievement
29	Engage with donors on CABI's new global programme that will incorporate Plantwise and Action on Invasives to secure new programme funding of £15m for 2020–2023 from existing and new donors	●	L		FCDO two-year funding £10.7m (largely for PlantwisePlus and other plant health projects); DEVCO €6m contract for PlantwisePlus Sept 2020–Dec 2023; DGIS £9m for PlantwisePlus; SDC £3m for PlantwisePlus (2021–2023, with in-principle support until 2030)
30	Support fund-raising from in-country donor country desks in Africa and Asia to secure co-support for implementation of CABI's new global programme, as well as ensuring ownership and linkages to other relevant initiatives	■	R	Only digital communication was possible and plans delayed to 2021	Koppert Foundation paid for validation of plant doctor training module on biocontrol in India, which was included in Plantwise training activities in Burundi, approved by The Netherlands (€400k). The same biocontrol training is also included in the Dutch project on potato value chain development in Kurdistan
31	Action on Invasives annual report submitted to donors and presented at annual Plantwise/ Action on Invasives donor forum	●	A	Donor forum held virtually	Annual donor report (2019) produced and shared with donors in Q1 2020. Virtual donor forum on 7 May, with representation from seven donors. Follow-up forum held on 13 October at CABI's Swiss centre with in-person participation of SDC and virtual participation of other donors

CABI's **Action on Invasives** programme aims to protect and improve the livelihoods of 50 million poor rural families impacted by invasive species through an environmentally sustainable, regional approach to comprehensive biological invasion management.

Action on Invasives is supported by:

UKaid from the British people

Ministry of Foreign Affairs of the Netherlands

Contact

To find out more, contact either of the following:

Roger Day, Action on Invasives Programme Executive
T: +44 (0)1491 829395
E: r.day@cabi.org

Janny Vos, Strategic Partnerships Director
T: +31 (0)33 4321031
E: j.vos@cabi.org

www.invasive-species.org **@CABI_Invasives**