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Horizon scanning for prioritising invasive alien species with potential to threaten agriculture and biodiversity in Ghana

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Abstract

Invasive alien species (IAS) continue to shape the global landscape through their effects on biological diversity and agricultural productivity. The effects are particularly pronounced in Sub-Saharan Africa, which has seen the arrival of many IAS in recent years. This has been attributed to porous borders, weak cross border biosecurity, and inadequate capacity to limit or stop invasions. Prediction and early detection of IAS, as well as mechanisms of containment and eradication, are needed in the fight against this global threat. Horizon scanning is an approach that enables gathering of information on risk and impact that can support IAS management. A study was conducted in Ghana to establish two ranked lists of potential invasive alien plant pest species that could be harmful to agriculture, forestry, and the environment, and to rank them according to their potential threat. The ultimate objective was to enable prioritization of actions including pest risk analysis, prevention, surveillance and contingency plans. Prioritisation was carried out using an adapted version of horizon scanning and consensus methods developed for ranking IAS worldwide. Following a horizon scan of invasive alien species not yet officially present in Ghana, a total of 110 arthropod and 64 pathogenic species were assessed through a simplified pest risk assessment. Sixteen species, of which 14 were arthropods and two pathogens, had not been recorded on the African continent at the time of assessment. The species recorded in Africa included 19 arthropod and 46 pathogenic species which were already recorded in the neighbouring countries of Burkina Faso, Côte d'Ivoire, and Togo. The majority of arthropod species were likely to arrive as contaminants on commodities, followed by a sizable number which were likely to arrive as stowaways, while some species were capable of long distance dispersal unaided. The main actions suggested for species that scored highly included full pest risk analyses and, for species recorded in neighbouring countries, surveys to determine their presence in Ghana were recommended.

Keywords
Horizon scanning, invasive arthropods, pathogens, pathway of introduction, pest prioritisation, pest risk analysis

Introduction

The spread of invasive alien species (IAS) has been increasing exponentially over the years, greatly facilitated by international trade and the global transport industry (Perrings et al. 2005; Meyerson and Mooney 2007). The International Union for the Conservation of Nature (IUCN) defines an alien species as a species, subspecies, or lower taxon introduced outside of its natural range and dispersal potential, i.e. outside the range it occupies naturally or could not occupy without intentional or unintentional introduction or care by humans (IUCN 2000). An alien species becomes invasive once it threatens biological diversity, food and economic security, and human health and well-being (Meyerson and Mooney 2007). In particular, IAS can cause significant economic damage through their negative effect on crop harvests and the sustainability of rural economies, thereby threatening livelihoods of hundreds of millions of people, especially in the developing world (Paini et al. 2016; Pratt et al. 2017).

In recent years, Sub-Saharan Africa (SSA), a region dominated by resource-poor farmers, has suffered from an increasing number of invasive plant pests. Eschen et al. (2021) estimated that the annual cost of IAS to agriculture in Africa reaches USD 65.58 Bn per year, with yield losses, reductions in livestock derived income and IAS management costs, mainly labour costs, constituting most of the estimated losses. In their study, the pest causing the highest yield losses (USD 9.4 Bn) was the fall army worm (*Spodoptera frugiperda*). This American pest was first recorded in Africa in 2016 and has since spread to SSA, threatening smallholder maize and sorghum production (De Groote et al. 2020; Tambo et al. 2020). Plant pathogens are also extremely damaging. For example, maize lethal necrosis, a disease caused by co-infection of *Maize chlorotic mottle virus* and *Sugarcane mosaic virus* was first reported in Kenya in 2011 but has since been reported in Democratic Republic of Congo, Ethiopia, Rwanda, and Tanzania (Mahuku et al. 2015; Mengesha et al. 2019; Kiruwa et al. 2020). The disease has had devastating effects on maize production in SSA (Mahuku et al. 2015; Boddupalli et al. 2020). Other plant pests recently reported in the region with devastating effects include tomato pinworm (*Tuta absoluta*) (Mansour et al. 2018), *Cassava brown streak virus* (Ferris et al. 2020), wheat stem rust (*Puccinia graminis* f. sp. *tritici*) (Fetch et al. 2016) and potato cyst nematodes (*Globodera rostochiensis* and *G. pallida*) (Mwangi et al. 2015; Mburu et al. 2020).

Increased trade between countries and regional blocks on the African continent has resulted in the spread of IAS once they have been reported on the continent (Nagoshi et al. 2018). It should also be noted that not all IAS invade Africa from overseas; some may be native to parts of Africa but are intentionally or unintentionally introduced to some countries or spread across the continent (Gezahgne et al. 2005; Roux and Coetzee 2005; Nakabonge et al. 2006). The spread of IAS from overseas and within the continent can be attributed to porous borders, weak cross border biosecurity, and inadequate capacity to limit or stop invasions (Early et al. 2016; Kansiime et al. 2017; Nagoshi et al. 2018; Graziosi et al. 2020). This exposes Africa both to repeated invasions from novel diseases, invertebrate pests and weeds and to continued spread across the continent once they have arrived (Day et al. 2017). Successful management of IAS involves prevention or early detection of invasions and ensuring effective management in case of arrival (Hulme 2006). Prevention of invasions remains the most cost-effective option of reducing impact of IAS (Wittenberg and Cock 2001; Leung et al. 2002). However, this requires an assessment of the highest risk species to enable the management of pathways of introduction, interception of movements at border points, and assessment of risk for planned imports (Simberloff et al. 2013). Once prevention fails and an IAS enters any jurisdiction, early detection, which allows for cost-effective removal, is important to institute eradication and containment interventions (Wittenberg and Cock 2001; Keller et al. 2007).

Horizon scanning for invasive species is an approach that provides countries with opportunities to gather information about IAS likely to head in their direction (Peyton et al. 2019). It involves the systematic search for potential IAS, their impacts on biodiversity, the potential to harm biodiversity, economic activities and human health, and opportunities for impact mitigation (Roy et al. 2014, 2019; Peyton et al. 2019, 2020). It is an important tool that contributes to prevent arrival, early identification and eradication of an IAS and is an essential component of IAS management with demonstrated net economic and ecological benefits (Keller et al. 2007; Caffrey et al. 2014). Horizon scanning has been used to determine the potential arrival, establishment and impact of invasive alien species in Europe (Roy et al. 2014, 2019; Gallardo et al. 2016; Peyton et al. 2019) and provides a practical and affordable option for African countries. The objective of this study was to employ horizon scanning to, firstly, establish a list of potential invasive alien plant pests (arthropods including insects and mites, and pathogens including fungi, bacteria, fungi and nematodes) that are considered not yet present in Ghana but may be harmful to Ghana's agriculture, forestry or environment if introduced. Secondly, to rank these arthropods and pathogens according to their potential threat, which will allow to prioritise actions including pest risk analysis, prevention, surveillance and contingency plans to mitigate the negative effects of introduced species (Peyton et al. 2019; Roy et al. 2019).

Methods

The prioritisation was carried out by a panel of 23 Subject Matter Experts (SMEs) from Ghana research institutions and academia with experience in entomology, bacteriology, mycology, nematology and virology. An adapted version of the consensus method developed for ranking IAS (Sutherland et al. 2011; Roy et al. 2014) was used to derive a ranked list of invertebrates and pathogens harmful to plants and likely to enter Ghana in the near future. The approach involved the following steps:

Step 1. Preliminary horizon scanning

The study started with a first workshop on 24–25th October 2019 in Accra, Ghana, during which the SMEs made a preliminary selection of pests that are not yet officially present in Ghana. This exercise was carried out using the premium version of the horizon scanning tool included in the CABI Crop Protection Compendium (CPC) (CABI 2020a). In this tool, information from the CPC datasheets is used to generate a list of species that are absent from the selected 'area at risk' but present in 'source areas', which may be chosen because they are neighbouring, linked by trade, or share similar climates. The list of species can be filtered using various criteria (e.g. pathways, habitats and taxonomy). The first scan provided the name of 1486 arthropods, nematodes and pathogens qualified as plant pests, present in Africa but absent from Ghana. The list was narrowed by selecting only the species with full datasheets in the CPC (to consider the most important pests) and included in the Invasive Species Compendium (ISC) (CABI 2020b), to eliminate those species in CPC that have not been reported as invasive anywhere and, thus, do not show any characteristics of invasiveness. This search provided 149 species of arthropods and 123 species of pathogens and nematodes, which were further discussed among two thematic groups (entomologists and pathologists/nematologists). During discussions, 63 arthropods and 77 pathogens/nematodes determined to be irrelevant to this exercise were removed, such as those that already occur in Ghana but were not listed as occurring in Ghana in the CPC, or those that were unanimously considered by the SMEs as not important for plants in Ghana, e.g. species that are specific to a plant genus that does not occur in the country. In contrast, 24 arthropod species and 18 pathogens/nematodes were added, in particular species that do not occur yet in Africa but are listed as quarantine pests by the National Plant Protection Organisation (NPPO) or species that had recently spread rapidly across other continents but not yet in Africa. Finally, a shortlist of 110 arthropods and 64 pathogens/nematodes was put forward for further assessment and scoring.

Step 2. Definition of a scoring system

At the same workshop in October 2019, the group of experts defined a scoring system, structured as a simplified Pest Risk Analysis (PRA). The system used by Roy et al. (2019) was modified according to the specificity of the prioritisation and tested, in groups, on some species. The final version of the scoring system is provided in the Suppl. material 1. It included questions on the likelihood of entry; likelihood of establishment; potential socio-economic impact; and potential environmental impact. Each of the four questions was scored from 1 (unlikely to enter or establish; and minimal impact) to 5 (very likely to enter or establish; massive impact). Each score for each question was defined.

The overall score was obtained by the following formula:

$$\text{Likelihood of entry} \times \text{likelihood of establishment} \times (\text{magnitude of socio-economic impact} + \text{magnitude of environmental impact})$$

In addition, the system also asked for information on the likely pathway of arrival (contaminant, stowaway and/or unaided, as defined by Hulme et al. (2008)). It was not possible to provide more detailed levels of pathways assessment because, for many species, the exact pathways of introduction and spread in Africa were not known. A confidence level was attributed to each individual score and the overall score following Blackburn et al., (2014). The likely pathway of arrival and the confidence levels were used to help focus discussions but were not used to build the final scores.

Step 3. Scoring of species

After a group training at the first workshop, the scoring of species was done remotely and independently by at least three assessors per species. The assessors were selected among the SMEs within each thematic group. Each expert assessed at least 20 species. The assessments were sent to the two thematic groups' coordinators who compiled all data and sent them to all assessors before the consensus workshop.

Step 4. Consensus workshop

On 27–28th February 2020, a consensus workshop was organised in Accra with the same experts who were involved in the initial scoring. All species were discussed separately in the two thematic groups. Discrepancies between scores were discussed among the three assessors of the species and the other experts. The assessors had the opportunity to modify their scores according to the opinion of the other experts. At the end, a final risk score was obtained for all assessed species by calculating the median score for all four questions and the final score as above. This score was validated by the group through consensus. In case of disagreement, the single scores were re-discussed. Species were then ranked according to their potential threat for Ghana. Some assessors who could not attend the second workshop were provided the possibility to comment on the scores by email after the workshop.

Step 5. Post workshop adjustments

After the workshop, discussions were carried out among the experts via email to assess, for the species that had scored high, what actions could be taken to mitigate them, e.g. PRA, prevention, surveillance or contingency plans. All experts had the opportunity to review the actions and add comments. In addition, in March 2021, all 174 species were screened again, by searching on the internet and through unpublished reports, to verify that the listed species had not been reported in Ghana since the second workshop.

Results

The full results of the assessments are provided in the Suppl. material 2 while the 40 species with the highest scores are provided in Table 1 and Table 2, which also presents the most suitable actions to be taken against them.

Arthropods

A total of 110 species were assessed, 101 insects and 9 mites. Fourteen species were not yet recorded in Africa at the time of assessment, 19 were already recorded in countries neighbouring Ghana (Burkina Faso, Côte d'Ivoire, and Togo) and 77 elsewhere in Africa. The scores varied from 12 to 160, the four highest scores (*Maconellicoccus hirsutus*, *Aleurothrixus floccosus*, *Liriomyza trifolii*, and *Thrips palmi*) being reached by species already present in neighbouring countries, thus likely to enter and establish, and known as important plant pests (Table 1 and Suppl. material 2). Only one mite, *Brevipalpus phoenicis*, was present with 19 insects in the 20 invasive alien arthropods considered to be highest risk. Among these, 11 were Hemiptera, three Diptera, two Thysanoptera, two Coleoptera and one Lepidoptera. The majority of the arthropods (95%) were likely to arrive as contaminants on commodities, i.e. on their host plants, but a sizeable number of them was also likely to arrive as stowaways (23%), whereas some good fliers already present in neighbouring countries could also enter unaided (Suppl. material 2). The most frequent suggestions for the most needed actions against the 20 species with the highest scores were full PRAs and surveys for the presence or introduction of the species in the country (Table 1). There were also a few cases of invasive species that have so far been identified to the genus level, for example *Liriomyza* spp. and *Thrips* spp., and for which sampling and proper identifications are needed.

Pathogenic organisms

In total, 64 pathogenic species were assessed: 14 bacteria (includes one phytoplasma), 16 fungi, 14 nematodes (Kingdom: Animalia), seven water moulds (Kingdom: Chromista), and 13 viruses (Suppl. material 2). Two of the 64 pathogenic species, *Moniliophthora perniciosa* and *M. roreri*, had not been reported anywhere in Africa

Table 1. The twenty Arthropod species with the highest scores in the prioritisation exercise and suggested actions.

Species	Order	Score	Suggested actions
Maconellicoccus hirsutus Green	Hemiptera	160	Surveys for its potential presence in Ghana
Aleurothrixus floccosus (Maskell)	Hemiptera	150	Surveys for its potential presence in Ghana
Liriomyza trifolii (Burgess)	Diptera	150	Since only *Liriomyza* sp. is reported in Ghana, *Liriomyza* spp. should be sampled in the country for molecular analyses and morphological ID to assess which species is present
Thrips palmi Karny	Thysanoptera	150	Since only *Thips* sp. Is reported in Ghana, *Thrips* spp. and related genera should be sampled in the country for molecular analyses and morphological ID to assess which ones are present in Ghana
Aonidiella orientalis (Newstead)	Hemiptera	140	Conduct a full PRA
Unaspis citri (Comstock)	Hemiptera	125	Surveys for its potential presence in Ghana and conduct a full PRA
Spodoptera eridania Stoll	Lepidoptera	120	Surveys with pheromone traps and sampling
Bemisia tabaci (Gennadius) (MEAM1)	Hemiptera	120	Sampling of *B. tabaci* in Ghana for molecular analyses to assess which sibling species is present
Brevipalpus phoenicis (Geijskes)	Trombidiformes	120	Conduct a full PRA
Callosobruchus chinensis L.	Coeloptera	120	Surveys to check if the species is not in Ghana. Because the other one is abundant
Dialeurodes citri (Ashmead)	Hemiptera	120	Conduct a full PRA
Diaphorina citri Kuwayama	Hemiptera	120	Conduct a full PRA
Dysmicoccus neobrevipes (Beardsley)	Hemiptera	120	A paper suggests that it may present in Uganda (only record in Africa), but the information is not clear. Ask the authors or specialists in Uganda
Icerya purchasi Maskell	Hemiptera	120	Check with Togo if the presence reported in Togo is confirmed. If yes, make surveys in Ghana
Liriomyza huidobrensis (Blanchard)	Diptera	120	Since only *Liriomyza* sp. is reported in Ghana, sample *Liriomyza* spp. in the country for molecular analyses and morphological ID to assess which species is present
Liriomyza sativae Blanchard	Diptera	120	Since only *Liriomyza* sp. is reported in Ghana, sample *Liriomyza* spp. in the country for molecular analyses and morphological ID to assess which species is present
Scirtothrips dorsalis Hood	Thysanoptera	120	Since only *Thips* sp. Is reported in Ghana, sample *Thrips* spp. and related genera for molecular analyses and morphological ID to assess which ones are present in Ghana
Trioza erytreae (Del Guercio)	Hemiptera	120	Conduct a full PRA
Aonidiella citrina (Coquillett)	Hemiptera	120	Check with Côte d'Ivoire if the recorded presence in Côte d'Ivoire is confirmed. If yes, make surveys in Ghana
Rhynchophorus ferrugineus (Olivier)	Coleoptera	112	Conduct a climate matching assessment and possibly a full PRA

at the time of assessment, leaving 62 pathogenic organisms with a presence in Africa. The agaricales *M. perniciosa* and *M. roreri*, which have potential to devastate the cocoa industry in Ghana, were only scored 60 (Suppl. material 2). These two species had a high likelihood of establishment and magnitude of socio-economic

Table 2. Pathogenic organisms with the highest scores in the prioritisation exercise and suggested actions.

Species	Kingdom	Score	Suggested actions
Xanthomonas oryzae pv. *oryzae* (Ishiyama) Swings, van den Mooter, Vauterin, Hoste, Gillis, Mew & Kersters	Bacteria	150	Survey for its potential presence in Ghana
Armillaria heimii (Pegler)	Fungi	150	Survey for its potential presence in Ghana
Thanatephorus cucumeris (Kühn)	Fungi	150	Survey for its potential presence in Ghana
Meloidogyne enterolobii (Yang & Eisenback)	Animalia	150	Survey for its potential presence in Ghana
Meloidogyne mayaguensis (Rammah & Hirschmann)	Animalia	150	Survey for its potential presence in Ghana
Maize dwarf mosaic virus	Virus	140	Survey for its potential presence in Ghana
Maize lethal necrosis disease	Virus	140	Conduct a full PRA
Clavibacter michiganensis subsp. *michiganensis* (Smith)	Bacteria	125	Survey for its potential presence in Ghana
Xanthomonas oryzae pv. *oryzicola* (Fang, Ren, Chen, Chu, Faan & Wu) Swings, Mooter, Vauterin, Hoste, Gillis, Mew & Kersters	Bacteria	125	Survey for its potential presence in Ghana
Tomato spotted wilt virus	Virus	125	Survey for its potential presence in Ghana and conduct full PRA
Banana bunchy top virus	Virus	120	Survey for its potential presence in Ghana and conduct full PRA
Cassava brown streak virus	Virus	120	Conduct a full PRA
Ralstonia solanacearum Race 2 (Smith)	Bacteria	105	Conduct a full PRA
Maize chlorotic mottle virus	Virus	105	Conduct a full PRA
Cocoa yellow mosaic	Virus	105	Survey for its potential presence in Ghana and conduct full PRA
Meloidogyne hapla (Chitwood)	Animalia	100	Survey for its potential presence in Ghana
Xanthomonas campestris pv. *musacearum* (Yirgou & Bradbury) Dye	Bacteria	90	Conduct a full PRA
Maize stripe virus	Virus	90	Survey for its potential presence in Ghana and conduct full PRA
Meloidogyne ethiopica (Whitehead)	Animalia	90	Survey for its potential presence in Ghana
Phytophthora vignae (Purss)	Chromista	84	Survey for its potential presence in Ghana

impact but a very low likelihood of entry and magnitude of environmental impact. Of the 62 pathogenic species, 16 had not been reported in countries neighbouring Ghana (Suppl. material 2). The 16 pathogenic species included four bacterial species, *Clavibacter michiganensis* subsp. *michiganensis*, *Leifsonia xyli* subsp. xyli, *Xanthomonas oryzae* pv. *oryzae*, and *Xanthomonas oryzae* pv. *oryzicola*; four fungal species, *Armillaria heimii*, *Olivea tectonae*, *Puccinia agrophila*, and *Thanatephorus cucumeris*; two nematode species, *Meloidogyne hapla*, *Meloidogyne mayaguensis*; four viral species, *Maize dwarf mosaic virus*, *Maize stripe virus*, *Sweet potato feathery mottle virus*, *Tomato potted wilt virus*, and one water mould, *Phytophthora cinnamomi*.

The overall score after considering all parameters ranged from 12, the lowest recorded for *Pseudomonas savastanoi* pv. *savastanoi* and *Ditylenchus dipsaci* to 150, the highest recorded for *Xanthomonas oryzae* pv. *oryzae*, *Armillaria heimii*, *Thanatephorus cucumeris*, *Meloidogyne enterolobii*, and *Meloidogyne mayaguensis* (Table 2; Suppl. material 2). The likely pathways of arrival of the assessed pathogenic species in Ghana were mainly two: as contaminants on commodities and/or as stowaways (Suppl. material 2). The majority (31, 48.4%) of organisms were likely to arrive in Ghana through both as contaminants or stowaways followed by those which could only arrive as contaminants (26, 40.6%) and lastly those which could exclusively arrive as stowaways. All fungi were likely to arrive in Ghana as contaminants on commodities (16), while seven could arrive as stowaways. All the assessed nematodes were likely to arrive as contaminants on commodities while three could also arrive either as stowaways or as contaminants. All the viruses could either arrive as contaminants or stowaways. Five of the bacteria species were likely to arrive as contaminant, five as stowaway and three as contaminants or stowaways. The only phytoplasma assessed was likely to arrive either as contaminants or stowaways. Four of the water moulds could arrive as contaminants or stowaways, while one could arrive as contaminants and two as stowaways, respectively. As for arthropods, in pathogens the most suggested actions for the high scoring species were to survey for their potential presence in Ghana, especially for species recorded in neighbouring countries and full PRAs (Table 2).

Discussion

The prioritization method used in this study was inspired from horizon scanning and prioritization of IAS (Roy et al. 2014, 2017, 2019; Bayón and Vilà 2019) and was used successfully to create two separate ranked lists of alien plant pests according to their potential threat for Ghana and to prioritize actions. The species with the highest scores were mostly those that scored high in the likelihood of entry, i.e. mostly those that were already recorded in neighbouring countries or spreading rapidly in Africa. It is logical that these species are prioritised and immediate actions taken through organising surveillance programmes. Species that were far from the country and were not spreading rapidly had a lower entry score that impacted the overall score, even though they could have serious effects if they arrived in Ghana. Examples of these species scoring low in likelihood of entry but high in impact included two cocoa pathogens, *Moniliophthora roreri*, the cause of frosty pod rot of cocoa (Phillips-Mora and Wilkinson 2007; Bailey et al. 2018) and *M. perniciosa* which causes “Witches broom disease” in cocoa (Meinhardt et al. 2008; Lisboa et al. 2020). Although *M. roreri* causes lower losses than some pathogens on a global scale due to its limited range, its economic impact in any epidemic ranks among the major pod pathogens (Ploetz, 2016). It is also ranked among the main yield-limiting factors of cocoa production in tropical America (Bailey et al. 2018). Severe outbreaks of *M. roreri* have resulted in abandonment of cocoa cultivation in extensive areas of Peru, Costa Rica, Colombia and Mexico (Phillips-Mora and Wilkinson 2007). In the 1970s, *Moniliophthora perniciosa* caused pod losses exceeding 90% in Rondonia, a Brazilian State, causing a significant socio-economic impact on the development of that State (Lisboa et al. 2020). In the State of Bahia, the pathogen was deliberately introduced in what is now considered an act of terrorism (“agro-terrorism”), which caused a reduction in production by almost 70% within 10 years (Saatchi et al. 2001; Caldas and Perz 2013; Lisboa et al. 2020).

The likelihood of establishment played a less important role in the prioritisation because species that are unlikely to establish because of unsuitable climate or absence of host plants were excluded in the preliminary sorting. Thus, most species scored high in the likelihood of establishment. The impact score also played an important role in the overall score, but mostly through their potential economic impact. Few species scored high in environmental impact, probably because most invasive plant pests in tropical regions are rather known for their economic impact and those that cause concern for non-commercial plants attract less attention and may pass under the radar of such horizon scanning. Many invasive arthropods are also known for their environmental impact (Kenis et al. 2009), but most of these are invasive predators such as ants and ladybirds, or pollinators. Nevertheless, some alien herbivorous arthropods and plant pathogens also have huge impacts on biodiversity and ecosystem functions worldwide, in particular those affecting tree species such as emerald ash borer, which has killed tens of millions of ash (*Fraxinus* spp.) in North America (Herms and McCullough 2014), hemlock woolly adelgid causing the decline of hemlock (*Tsuga* spp.) in North America (Ellison et al. 2018), box tree moth, which decimates wild box stands (*Buxus sempervirens*) in Europe (Mitchell et al. 2018), and the pathogens causing chestnut blight (Rigling and Prospero 2018), Dutch elm disease (Harwood et al. 2011), and ash dieback (Mitchell et al. 2014), which have had a dramatic impact on chestnut (*Castanea* spp.), elm (*Ulmus* spp.) and ash, respectively, in North America and Europe. Some serious invasive tree pests such as the sirex woodwasp (*Sirex noctilio*) (Tribe and Cillié 2004), Eucalyptus long-horned borers (*Phoracantha semipunctata* and *P. recurva*) (Paini et al. 2016), Cypress aphid (*Cinara cupressi*) (Watson et al. 1999), Coniothyrium stem canker (Gezahgne et al., 2005) and pink disease caused by *Erythricium salmonicolor* (Roux and Coetzee 2005) have also been recorded in Africa but mostly concern exotic trees. An exception is *Euwallacea fornicatus*, a wood-boring beetle from Asia that damages many native trees in South Africa (Paap et al. 2018).

Several alien arthropods and pathogens were identified in neighbouring countries, which suggests that some of these species may already be present in Ghana but have not yet been recorded or identified to the species level. It is essential that these species are sampled and identified using morphological and molecular methods. This could be the case for some species that reached high scores in the assessment. For instance, *Maconellicoccus hirsutus* is a scale insect that is a serious pest of cocoa (Fornazier et al. 2017), a key crop in Ghana. It is present in all three neighbouring countries, but not yet officially reported in Ghana. Another typical example is that of the leaf mining flies of the genus *Liriomyza* (Parrella 1987; Lee et al. 2004; Migiro et al. 2010). Three species of this genus, *L. trifolii*, *L. huidobrensis* and *L. sativae*, are notorious for being invasive and all are alien in Africa (Radcliffe and Lagnaoui 2007; Migiro et al. 2010; Akutse et al. 2013; EFSA Panel on Plant Health et al. 2020b). However, so far, only "*Liriomyza* sp." has been reported in Ghana (Garmonyou et al. 2014) although *L. sativae* has been intercepted in the European Union on products from Ghana, suggesting that it is present in the country (EFSA Panel on Plant Health et al. 2020b). Similarly, the highly invasive thrips, *Thrips palmi* (Cannon et al. 2007; EFSA Panel on Plant Health et al. 2019) is reported from neighbouring countries and it is known that *Thrips* spp. cause serious damage to vegetables in Ghana (Baah et al. 2015), but it is not clear what species are present in the country. The whitefly *Bemisia tabaci* is known to be a complex of many sibling species, several of them being highly invasive worldwide (Perring 2001; Vyskočilová et al. 2018). These species can only be identified using molecular tools (Vyskočilová et al., 2018) and it is not clear to which species of the *Bemisia tabaci* complex the numerous records in Ghana refer.

Species that are most probably not yet present in Ghana but already in neighbouring countries or spreading fast on the continent may require implementation of surveillance programmes, which could either be based on visual surveys or trapping campaigns (Berec et al. 2015; Ward et al. 2016). An example is *Spodoptera eridania*, found in Africa in 2016 and already present in several African countries including Nigeria and Benin (Goergen 2018; EFSA Panel on Plant Health et al. 2020a). There is uncertainty regarding the risk of several species, either because the likelihood of entry and establishment is unclear or because the potential impact is difficult to assess. In such cases, a full PRA would be needed. Pest risk analyses may also be needed for species that are undoubtedly considered as high-risk pests but require quarantine measures that can only be justified based on full PRAs carried out following international standards.

When assessing risks, it is important to supplement the answers with a confidence level, or a level of uncertainty (Holt et al. 2014). Our simplified PRA system asked assessors to provide a confidence level for the answers, both for the single scores and for the overall score. However, the overall confidence level provided by the entomology and pathology groups (Suppl. material 2) were very different, i.e. the pathology group considering that the overall scores for pathogens and nematodes were obtained mostly with high confidence whereas the entomology group was more cautious and provided mostly medium confidence levels for arthropods, although there is no reason to believe that data on arthropods are less reliable than those on pathogens and nematodes. Moreover, the levels of confidence provided by the different assessors for the same questions using the same information sources often differed from high to low, suggesting that, in the future, instructions for the scoring of confidence levels should be more clearly defined.

Conclusion

We have demonstrated that through horizon scanning, a country can identify potential invasive plant pests, both invertebrates and pathogens, and use the information to determine the risk associated with each. This will enable the country to invest the limited resources in priority actions such as preventing arrival and establishment of IAS, PRAs, surveillance and developing contingency plans. This study can serve as a model for future projects on plant pests' prioritisation in Africa and elsewhere. It would be applicable for assessing the risk of invasive plant pests in any country or region, e.g. trade blocks, with minor modifications of the method, particularly in the mini-PRA protocol used to score species.

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Supplementary material 1

Guidelines for horizon scanning for plant pests potentially threatening Ghana

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Data type: Guidelines for horizon scanning.

Explanation note: Guidelines for the horizon scanning method used to score potential invasive alien plat pests in Ghana.

Link: https://doi.org/10.3897/neobiota.71.72577.suppl1

Supplementary material 2

Risk scores for potential invasive alien plant pests in Ghana

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Data type: Risk scores.

Explanation note: Risk scores for all species assessed in the horizon scanning of potential alien invasive plant pests in Ghana.

Link: https://doi.org/10.3897/neobiota.71.72577.suppl2