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Invasive Plant Pests Threatening Ethiopian Agriculture

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Proceedings of the 17th Annual Conference

Edited by:

Bayeh Mulatu

Plant Protection Society of Ethiopia

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Proceedings of the 17th Annual Conference

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Bayeh Mulatu

PPSE MoA EIAR FAO

The Plant Protection Society of Ethiopia is a society formed by plant protection professionals in the country and is licensed and registered by the Charities and Societies Agency of the Ministry of Justice. The society has been in existence for more than two decades and has been conducting annual conferences every year by picking up a key plant protection issue of a year as a theme. Accordingly, the theme for the 17th annual conference of the Society was 'invasive alien pests of plants threatening Ethiopian agriculture'. Papers on the theme were presented by eight invited contributors in the plenary session of the 2010 annual conference. Six of the presentations are compiled into this proceedings book.

The 17th annual conference was organized by the 2010 and 2011 PPSE executive committee members:

1. Dr. Bayeh Mulatu, President
2. Dr. Eshetu Ahmed, Vice President, (Deceased)
3. Dr. Tebkew Damte, Secretary
4. Mr. Lidet Sitotaw, Finance Officer
5. Dr. Mulugeta Negeri, Cashier
6. Dr. Melaku Alemu, Auditor

Current PPSE Executive Committee Members

1. Dr. Gashawbeza Ayalew, President
2. Dr. Adane Abraham, Vice President
3. Mr. Tariku Hunduma , Secretary
4. Mr. Berhanu Bekele, Finance Officer
5. Mrs. Hiwot Lemma, Treasurer
6. Mr. Yeraswork Yilma, Auditor

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ISBN: 978-99944-987-3-4

Correct citation: PPSE (Plant Protection Society of Ethiopia). 2012. Invasive Plant Pests Threatening Ethiopian Agriculture. Proceedings of the 17th Annual Conference, November 26-27, 2010, Addis Ababa.

Contents

Preface

The Plant Protection Society of Ethiopia (PPSE) is a civic society registered by the Charities and Societies Agency of the Ministry of Justice. The Society held its 17th annually conference between Nov 25 and 26, 2010 on the theme "**Invasive Pests of Plants Threatening Ethiopian Agriculture**".

This theme has been chosen because of its timeliness as the country is focusing to significantly improve the economic power of its peoples through increased production and export of different cash crops that include: oilseeds, pulses and horticultural crops. Moreover it is picked at the time when the government of Ethiopia put the five years national Growth and Transformation Plan (GTP) into action and is working towards its accomplishment within the coming less than five years.

As the backbone of the country's economy a lot is expected from the agriculture sector in terms of boosting agricultural production and productivity and increase agricultural exports, which has to be improved continually through strategic approaches. Therefore, in order to sustainably increase the country's export earnings from agricultural produces, we need to guard against invasive alien species that may come on our way and derail our progress. This requires creating increased awareness among all the relevant stakeholders, which include public sector institutions, non state development actors and civic societies. Although the primary responsibility lies on institutions in the public agriculture sector, as a professional society, the plant protection society of Ethiopia also shares both the vision and the responsibility. This society of primarily plant protection professionals is committed to the realization in the country at large and that was the reason why the executive committee picked the above described theme for the 17th annual conference, which was successfully held on the affixed dates at the Hiruy hall of the Ethiopian Institute of agricultural Research for 2 days between November 26 and 27 2010. And this proceeding contains the welcoming address, and full write-ups of papers presented in the plenary session and critical issues raised in the plenary session and the recommendations reached at.

Welcome Address

By Bayeh Mulatu
President, Plant Protection Society of Ethiopia
At EIAR in Hiruy Hall
November 26, 2010 at 03:00 am

Dear Honorable Guests and Conference Participants,
On behalf of the executive committee I welcome you all to the 17th annual conference of the Plant Protection Society of Ethiopia. As you all have understood the theme of the conference is about invasive alien pests of plants threatening Ethiopian agriculture.

It is common knowledge that bio-geographical barriers that once restricted species to specific areas or regions have been circumvented, leading to increased homogenization of the Earth's biota. The movement of species has been done intentionally by man or as unintended companions to goods traded within a country, between neighboring countries, within a continent and between continents. For instance, according to the World Trade Organization, during the past 50 years the growth in air travel passenger numbers increased approximately 9% per annum. Since 1993, shipping traffic has increased by 27%. In addition, agricultural exports have increased in value from US $ 568 billion in 1998 to US $ 1.128 trillion in 2007. It is cheaper and more efficient shipping and communications technologies and growing consumer demand that have led to a surge in global trade in the past half-century.

These globalizations of commerce, transportation, human migration, and recreation in recent history have introduced invasive alien species (IAS) to new areas at an unprecedented rate. Most invasive alien species, including many of our sources of food and fiber are not harmful; and many are highly beneficial. A small percentage of IAS causes great harm to the environment, the economy or human health.

The conference theme was chosen because of its timeliness as the country is focusing to significantly improve the economic power of its peoples through increased production and export of different cash crops that include: oilseeds, pulses, horticultural crops, and different imported high value crop species such as roses and herbs. Therefore in order to remain competent in the ever expanding global market that has the appetite for agricultural produce of the highest quality, we need to present produces, which meet the set quality

requirements. Thus one of the most important actions we have to take is protect our agriculture from the threat of invasive alien species that could affect the export market and also what we produce to meet our domestic needs. Moreover we need to strengthen our quarantine systems both local and international for same cause. This requires creating increased public awareness among all the relevant stakeholders. As a society of plant protection professionals we are committed to its realization in the country at large.

Dear Honorable Guests and Conference Participants,

Before leaving the podium to the chairman of this opening session, Dr. Solomon Assefa, director general of EIAR, I would like to acknowledge our sponsors. This conference was possible because of the unreserved financial and facility support the society received from the following public and private institutions:

1. Ethiopian Institute of Agricultural Research (EIAR)
2. Ministry of Agriculture (MoA)
3. Food and Agriculture Organization of the United Nations
4. Syngenta
5. Sasakawa Global 2000 (SG2000)
6. Kaleb Farmer House Plc.
7. Chemtex Plc.,
8. Axum Greenline Plc.
9. Adami Tulu Pesticide Processing Industry

After saying these, respectfully, I call upon Dr. Solomon Assefa to invite our guest of honor his Excellence's (Ato Wondirad Mandefro) representative, Dr. Berhe Gebre Eghziabher to the podium and deliver the opening speech to this esteemed gathering.

Thank you all again for your coming to attend this annual event.

Opening speech

By H.E. Ato Wondirad Mandefro
At 08:50-09:10 am, November 26 2010

Delivered by the Minister *de eta* representative, Dr. Berhe Gebre Eghiziabher

It is indeed an honor and a great pleasure for me to have been invited by the plant protection society of Ethiopia to give an opening speech on the 17th annual conference themed "Invasive alien pests of plants threatening Ethiopian agriculture".

Dear Honorable Guests and Conference Participants

The spread of IAS is creating complex and far-reaching challenges that threaten both the natural biological riches of the earth and the well being of its citizens and are directly linked to the replacement of dominant native species, the loss of rare species, changes in ecosystem structure, alteration of nutrient cycles and soil chemistry, shifts in community productivity, reduced agricultural productivity and changes in water availability. The case in point for Ethiopia is what Prosopis is doing to the dry land ecology in the Afar region.

It is confirmed that invasive species are second only to habitat destruction as a threat to biodiversity. Consequently, the dynamic relationship of IAS among plants, animals, soil and water established over many thousands of years are at risk of being destroyed in a relatively brief period.

As global climate patterns shift, the distribution of species will change, and particular habitats may become more or less susceptible to the impacts of new species introductions.

While the problem of IAS is global, the nature and severity of the impacts on society, economic life, health and natural heritage are distributed unevenly across nations and regions. Thus, some aspects of the problem require solutions tailored to the specific values, needs, and priorities of nations while others call for consolidated action by the larger world community. In relation to this again the Prosopis invasion in the Afar region is a problem that requires tailored solutions that could fit very well with the life style of the Afar people. This is possible mainly with the full and direct participation of the Afar people so that their way of life could be maintained by reducing the negative effects Prosopis brought to their areas. Dealing with this challenge decisively will help us to

prevent other alien invaders from coming and destroying our diverse ecologies. In general preventing the movement of IAS and coordinating timely and effective responses to invasions will require cooperation and collaboration amongst governments, economic sectors, non-governmental organizations, and international treaty organizations.

While both the problem and the scale of the solution may appear dauntingly complex, the issue presents an unparalleled opportunity to respond with actions that link preservation of biodiversity with protection of the health and livelihood of the world's human populations. Accordingly Ethiopia strives and takes this step to play its share in preventing or minimizing the adverse impacts of IAS nationally.

Dear Honorable Guests and Conference Participants

In Ethiopia work on IAS has been coordinated under the MoAD by the animal and plant health regulatory directorate which is mandated to carry out risk analyses, early detection, rapid response, processing import permits, pest management, monitoring and evaluation, early warning services such as transfer of information and knowledge to farmers, development agents, agricultural experts and custom officers of the occurrence of incipient populations of new IAS in a certain corner of the country. Despite all the efforts, in the past four decades over 20 dangerous pests have been introduced into the country, which include several insect pests, disease causing pathogens and weed species. Specific examples are prosopis and parthenium, the cypress aphid and pea weevil and citrus canker.

Owing to the very wide altitudinal range Ethiopia is endowed with different climatic zones that are favoring the growth of diverse plant, animal and microbial species. Because of the availability of different favorable environments, incoming nonnative species have a very high chance of establishing themselves. Some of such species may become invasive thus may affect the native biodiversity and also the quality of agricultural produces and the overall economy of the land. This is aggravated by the long boarder distances the country shares with its neighboring countries and the porosity of the borders, which has been favoring the free flow of people, animal and plant and plant products, hence serving as a major pathway for unintentional introduction of organisms of quarantine significance into the country heartland.

The custom and quarantine posts are few in number and are not much to the numerous cross border informal trade routes hence we have experiences of not

being efficient in inspecting and intercepting all potential invasive species coming through the different pathways described above. Moreover, the least emphasized domestic quarantine has also been contributing to the further spread of introduced invasive species and resident pests to new areas in the country in a very short period of time. Therefore we have to work to put in place a mechanism to scale back significantly the movement of planting materials carrying pests of economic importance from one corner of the country to another by establishing an efficient internal quarantine system.

It is common knowledge that there have been several huge relief efforts carried out in the country in the past about four decades. This has also been one more pathway for the introduction and spread of nonnative plant species some of which became invasive species such as parthenium.

The other pathway has been the introduction of planting materials for various purposes. As you all know there are emerging new crop technologies that are of immense economic benefit to the country and are being introduced in huge volumes for direct production. This include biofuel plants, flowers, food crops like rice, maize, vegetable and fruit species, which may bring with them IAS because of the difficulty of making appropriate inspection to intercept species that may become invaders. Therefore in order to continue benefiting from the ever expanding global market for goods and services we need to have placed more robust quarantine system. The Ministry of Agriculture Development with all its partners is doing this so that invasive and quarantine pests free zones could be maintained and we continue benefiting from important foreign exchange generating crops.

Dear Honorable Guests and Conference Participants

I made my speech to be focused on the threat of invasive alien species because it is a threat to our vision of becoming a middle income country by exploiting all possible avenues that could bring to us many riches.

Areas that require attention are not limited to invasive alien species. Many of the resident pests on various crops of economic benefit are causing economic damage. The most recent ones are the sweet potato viruses on sweet potato and the stem and yellow rusts of wheat. What this tells us is that we still need to work on management of resident pests, which requires due emphasis by the research system. Therefore we need to strengthen further the work on disease causing pathogens, insect pests, weeds and other crop husbandry practices.

Dear Honorable Guests and Conference Participants

Before concluding my speech I want you all to contribute to the growth and development plan the Federal government put forth and is going to implement it in the coming five years. Therefore you are expected to work more than ever to protect our crops from the ravage of pests so that we will produce more to export as well feed ourselves. After having said this now I call the 17th annual conference of the plant protection society of Ethiopia officially opened and I wish you successful deliberations.

Thank you all

Citrus canker (*Xanthomonas axonopodis* pv. *citri)* and Huanglongbing (greening) (*Candidatus liberibacter*) Invasive Citrus Diseases in Ethiopia

Eshetu Derso and Binyam Yalemtesfa*

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Introduction

The human population and its food demands are increasing at an annual rate of 1.4%. Although world population will probably stabilize by the year 2050, this will require an increase of about 25% (Abesha and Gustavo, 2004) in plant productivity. These demands can be partially met by diminishing the impact of invasive pest and pathogens which represent 12% (James *et al.*, 1990) of the productivity.

It is well recognized that threats by invasive pathogens such as *Xanthomonas* and *phythoplasmas* to horticultural commodities are increasing as a result of loose quarantine system, globalization, increased human mobility, climate change, and pathogen and vector evolution. These factors have combined to increase the spread of invasive plant pathogens (Anderson *et al.*, 2004). Taken in total with damage caused by emerging, re-emerging (e.g., new races, pathotypes, forms resistant to pesticides or antibiotics), and chronic/endemic pathogens, the potential for economic loss is significant in plant systems (Strange and Scott, 2005).

Governments are responsible to protect agricultural and natural plant systems in their countries from invasive pathogens, while at the same time putting in place measures to prevent their own endemic pathogens from becoming invasive species in others. Although the private sector has a responsibility to produce clean plant products, safeguarding of agricultural and natural plant systems from introduced pathogens is usually considered a public good, and therefore a role of the government (Sheldrake and Turner, 2003).

Plant disease diagnostic networks have developed worldwide to address the problems of efficient and effective disease diagnosis and pathogen detection, engendering cooperation of institutions and experts within countries and across national borders. Networking maximizes impact in the face of shrinking government investments in agriculture and diminishing human resource capacity in diagnostics and applied pathology (Smith *et al.*, 2008). New

technologies promise to improve the speed and accuracy of disease diagnostics and pathogen detection.

Subsequently, it appears that, early and accurate diagnoses and pathogen surveillance on local, regional, and global scales are necessary to predict outbreaks and allow time for development and application of mitigation strategies.

Citrus is an extremely important crop on a worldwide basis, and is grown wherever the climate is suitable. Total worldwide production of citrus is estimated at over 73 million metric tones (Wayne, 2001).

Citrus is widely grown in Ethiopia and most cultivation in the south and south-west region is based on a small number of local varieties and in most parts of the country it is grown by small scale producers with plantings of, often, less than 50 trees and on large scale plantations as well (Eshetu, 2006). Small scale commercial farms belonging to Federal Prison, Horticulture Development Enterprise, Agriculture Development Enterprises and others also produce citrus, for export to regional markets and local Agro-industries. Most of the citrus in commercial farms is produced by the Upper Awash Agro Industry Enterprise (UAAIE) which includes Merti Jeju, Nura Era, Tibila, and Awara Melka (Seifu, 2003). Citrus is also grown in Metehara, Melka Werer , Error Gota Gibe, Jima, Mizan Teferi, Bebeka, Tepi, Metu, Shewa Robit and Tisabalima (Seifu, 2003; Eshetu, 2006). However, the predominant citrus is produced by small scale producers in the various regions of the country.

Citrus canker and Huanglongbing (HLB) or citrus greening are two very serious diseases that occur in different parts of the world. Both diseases are labeled as threats because of their impact on yield (quantity or quality) and international trade, ability of the pathogens to survive and to spread rapidly, difficulty in controlling with available technology, and very high cost of disease management practices,

This paper discusses different aspects of citrus canker (*Xanthomonas axonopodis* pv. *citri)* and citrus Huanglongbing (greening) disease (*Candidatus liberibacter)* that are currently becoming invasive and devastating. Unfortunately, the two diseases are becoming threats to citrus production in various parts of Ethiopia in general, and in the Rift Valley, in particular. Advises on basic principles of management of these diseases is also suggested.

Citrus canker (*Xanthomonas axonopodis* pv. *citri,*)

Of all the agricultural pests and diseases that threaten citrus crops, citrus canker, caused by the bacterium *Xanthomonas axonopodis* pv. *citri,* is considered one of the most devastating and feared disease affecting all types of important citrus crops (Gottwald *et al.,* 2002) and is a highly contagious disease in many parts of the world. An infestation can destroy entire crop (USDA, 1997). It is the most important and a very destructive disease the eradication of which has received considerable press attention and legal challenges and has produced far-reaching political and socioeconomic impact in some countries and has implications for national and international trade (Gottwald *et al.,* 2001).

Taxonomy and nomenclature

The disease is caused by an invasive bacterial plant pathogen species known as *Xanthomonas axonopodis* pv. *citri,* (syn=*Xanthomonas citri* ex Hasse (syn = *X. campestris* pv. *citri* Dye pathotype A, *X. aurantifolii* pv. *citri* pathotype A) and *X. campestris* pv. *aurantifolii* Gabriel (syn = *X. campestris* pv. *citri* Dye pathotypes B and C, *X. aurantifolii* pv. *aurantifolii* pathotypes B and C (Schubert *et al.*, 2001; Gotto *et al.,*1980). The Taxonomic status of the citrus canker bacterium classifies it as a Proteobacteria, gamma subdivision, Xanthomodales, *Xanthomonas* group, *axonopodis* DNA homology group, *X. axonopodis* pv. *citri* (Hasse) (Vauterin *et al.*,1990). Several forms of the disease are recognized. It is believed that four forms of citrus canker (A, A*, B, and C) occur around the world and are induced by variants of the same causal agent. These variants are primarily distinguished by their geographical origin and their host range (Pruvost *et al.*, 1992).

Symptoms Although its appearance may vary on different varieties and under different weather conditions, it is characterized by the formation of circular, water soaked lesions that become raised and blister-like, growing into white or yellow spongy pustules that then darken and thicken into a light tan to brown corky canker which is rough to the touch (Figure 1). On heavily infected trees, citrus canker causes defoliation and premature fruit drop; an essential diagnostic symptom is citrus tissue hyperplasia (Gabriel, 2001).

Figure 1 Citrus canker symptoms on leaves fruit and twigs

Disease cycle The bacterium propagates in lesions in leaves, stems, and fruit. When there is free moisture on the lesions, bacteria ooze out and can be dispersed to new growth and other plants. Rainwater collected from foliage with lesions contains between 10^5 to 10^8 cfu/ml. Wind-driven rain is the main natural dispersal agent, and wind speeds ≥18 mph (8 m/s) aid in the penetration of bacteria through the stomatal pores or wounds made by thorns, insects such as the Asian leaf miner, and blowing sand. All aboveground tissues of citrus are susceptible to *Xac* when they are young and at maximum susceptibility during the last half of the expansion phase of growth (Gottwald *et al*., 2002).

Host Range and Geographic Distribution Plants of the genus *Citrus* are known to be susceptible to citrus canker in varying degrees and the family *Rutaceae* have also been reported as host plants for *X. campestris* pv. *citri* by artificial inoculation. However, most except *Poncirus trifoliata* are not sufficiently susceptible under normal conditions to warrant attention (Goto, 1992). Among citrus cultivars and rootstocks, citrus canker is most severe on grapefruit, some sweet oranges such as hamlin, pineapple, and Navel, Mexican (Key) limes and lemons, and trifoliate orange [*Poncirus trifoliata* (L.) Raf.] and their hybrids that are used for rootstocks.

Citrus bacterial canker probably originated in South-East Asia. Subsequently, the pathogen was disseminated throughout Asia, and then to Africa (Eshetu, 2006), Oceania and South America. In recent years, the disease has occurred in islands in the Indian Ocean, in the Middle East and in North America.

Occurrence of citrus canker in Ethiopia was first recorded in 2004 (Eshetu, 2005).

New emergence of the disease, Atypical Asiatic (Pathotype A*) was recorded in Ethiopia, While in Somalia and Mali typical Asiatic or pathotype "A" was reported. Reemergence of the disease was also reported from Australia (Figure 2).

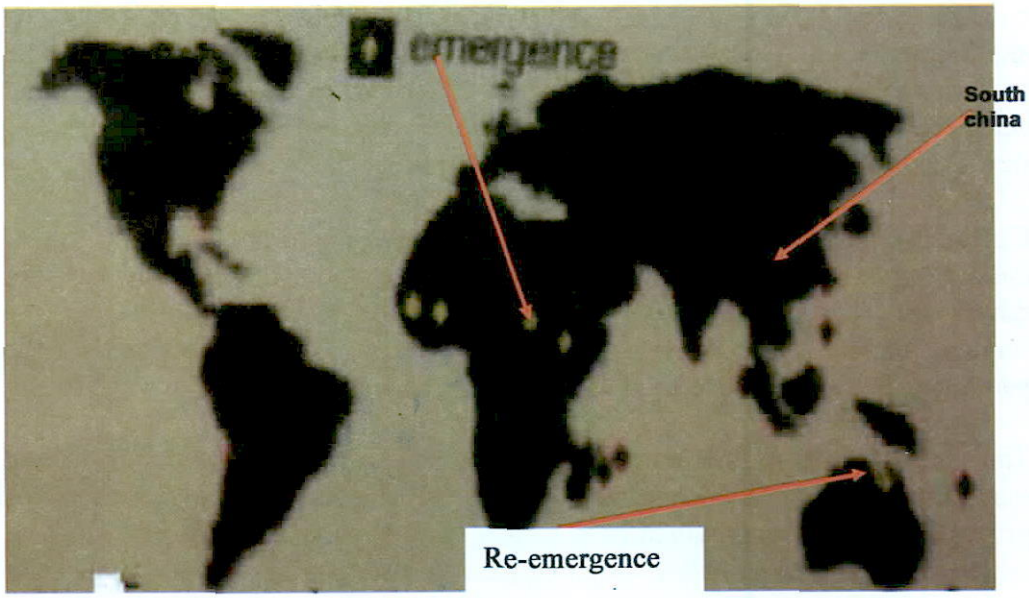

Figure 2 Worldwide distribution of citrus canker *X. axonopodis* pv.*citri*

Means of Dispersal *X. axanopodis pv.citri* pathogen does not require a specific vector but can be transmitted from plant to plant via wind, rain and human-derived materials such as contaminated cutting tools and infected plant clippings (Yang and Gabriel, 1995). Long-distance dissemination of the pathogen occurs primarily via the movement of infected planting and propagating material, such as bud-wood and rootstock seedlings or budded trees from nurseries. There is no confirmed record of seed transmission.

Disease management

Regulatory Control Considerable regulatory effort should be directed at preventing the introduction and spread of canker because it is not present in all

citrus growing regions of the world where the moist, sub-tropical to tropical climate is conducive to disease development (Gottwald and Graham, 1992).

Eradication of citrus canker and the subsequent restriction on importation of citrus fruits from regions where citrus canker is endemic comprises a typical example of regulatory control of plant diseases (Goto, 1992). Safeguards for exporting citrus fruits into importing countries include: the establishment of isolated canker-free export areas; inspection of fruit by plant pathologists in both countries during harvesting and packing operations; pre-shipping surface sterilization with bactericidal dip; pre-shipping inspection using the bacteriophage method to ensure fruits are free of *X. axonopodis* pv. *citri*; and certification by the respective countries Plant Protection Service that fruits are free of *X. axonopodis* pv. *citri* (Goto, 1992).

Cultural Control: The disease has attracted widespread attention because of the serious efforts that have been made for eradication; these include cutting down and burning infected, mature trees on a large scale and the implementation of strict international plant quarantine regulations against the pathogen (Stall and Civerolo, 1991; Goto, 1992).

The use of canker-free nursery plants is the first essential step in the management of citrus canker. Windbreaks are also established around citrus groves. Angular shoots which hold canker lesions should be pruned. The leaf miner, *Phyllocnistis citrella*, which can cause infection sites, is controlled by periodic spraying with insecticides (Goto, 1992).

Biological Control: Interactions between *X. axonopodis* pv. citri and antagonistic bacteria including *Bacillus subtilis* (Pabitra *et al.*, 1996), *Pantoea agglomerans* (Goto, 1992), *Pseudomonas syringae* (Ohta, 1983) and *P. fluorescens* (Unnamalai and Gnanamanickam, 1984) have been reported in vitro and in vivo. However, the practical usefulness of these bacteria in controlling the pathogen has not been so far proved.

Chemical Control The disease cannot be controlled by chemicals after it has reached epidemic proportions. Therefore, the prevention of primary infection on spring shoots is emphasized; this is achieved by spraying copper compounds for a few months, as preventive application, beginning just before the first flush until the leaves completely unfold (Goto, 1992). However, frequent spraying imposes a great burden on citrus growers and not economically feasible. To reduce spraying frequency, all control methods must be combined functionally

into an integrated control system (Agrios, 2005). In general, chemical control of diseases caused by phytopathogenic prokaryotes is made difficult because of short generation times (Lacy and Felix, 2004).

Early Warning Systems A forecasting system has been adopted in many countries. The number of overwintered lesions on angular shoots is determined and meteorological data such as temperature, precipitation and wind velocity are monitored from autumn through to early spring; these factors are responsible for the build-up of bacterial populations in citrus groves. Outbreaks of the disease can be predicted 1-2 months in advance (Goto, 1992).

Status of citrus canker in Ethiopia

In Ethiopia, The occurrence of the disease was first reported in the Rift Valley (Eshetu et al., 2005) and was observed only on Mexican lime (*Citrus aurantifolia)*. At that time, mean disease incidence in this area on leaves was 71.4% and severity was 26.8%; incidence on fruits was 30% and severity 21.25%. This was the first confirmed report of the disease in Ethiopia (Eshetu 2006). Recently, citrus canker was recorded at Melkassa, and Debre Zeit, both in Oromia region. In Amhara region it was recorded on farmers' orchard in Shewa Robit and also at Jari. High disease incidence on leaves, 75%, and severity, 45% were observed at Jari followed by Shewa Robit and Melkassa. Relatively low diseases incidence, 40%, and severity, 25%, were observed at Debre Zeit. Moderate disease severity was also observed in Somali region, Shinele zone, and in Harari region, 15-20% and 10% respectively (Table 1). The host range for citrus canker in Ethiopia is so far limited to Mexican lime (*C. aurantifolia*). It appears that the *X. axonopodis* pv. *citri* variant that occurs in Ethiopia has similar host ranges to that of atypical Asiatic , which has also been described in the Middle East region and India (Eshetu and Kamaruzaman, 2007). In the other part of the world, citrus canker was believed to be a low land disease (Gottwald *et al.*, 2002). However, in Ethiopia the disease was recorded at elevation ranging from 800m at Melka Werer to 1900m at Debre Zeit (Table 1). This confirms the larger geographical distribution of the citrus canker pathogen (Figure 3).

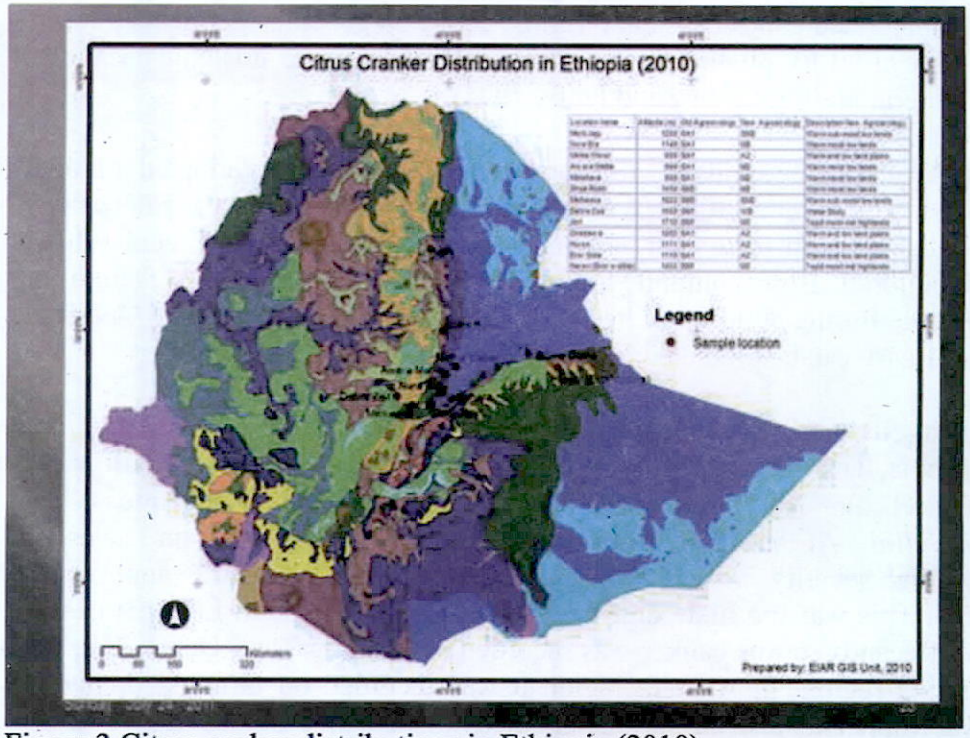

Figure 3 Citrus canker distributions in Ethiopia (2010)

Further studies were also conducted with the objective of monitoring the disease spread, identifying, characterizing and determining the genetic diversity of the *X. axonopodis* pv. *citri* strains from Ethiopia on the basis of their pathogenecity, biochemical, physiological, and molecular properties (Eshetu and Vernier, 2009b). On the basis of pathogenecity, biochemical and physiological tests, PCR identification, ISLM-PCR and MLVA analysis, Ethiopian strains of *X. axonopodis* pv. *citri* were closely related to pathotype A* and not to pathotype A. To our knowledge, this is the first confirmed report of the presence of pathotype A* on the African continent. This could allow studying the epidemiology of pathotype A* strains in a unique situation where they do not compete with pathotype A strains (Eshetu *et al*., 2009a). Further monitoring of the disease spread is currently in progress in parts of the country where previous surveys were not conducted.

Table 1 Geographic distribution and Citrus canker (*X. axonopodis* pv *citri)* severity in Ethiopia

Locations	Latitude	Longitude	Elevation (m)	Disease severity	
				Leaves (%)	Fruits** (0-4 scale)
Merti Jeju	08°34"	39°40"	1250	17.3d (12.7-23)	1.5 (0-2)
Nura Era	08°50"	39°54"	1140	24.8 bc(16.7-34.9	nf
Melka Werer	09°20"	40°10"	800	25.6c (11.9-34.4	1.4 (0-2
Awara Melka	09°10"	39°59"	960	35.9a (26-44.2)	1.5 (0-3)
Metehara	08° 48"	39° 52"	950	25.3b	1(0-2)
Shoa Robit	10°01"	39°54"	1450	40a	2 (1-3)
Melkassa	08°33"	39°17"	1622	30ab	1.4 (1-2)
Debre Zeit	08° 44"	38° 58"	1900	25b	1 (0-2)
Jari	11°40"	39°39"	1710	45a	2.5 (2-3)
Diredawa	09° 33"	41° 51"	1202	13.2	1 (0-2)
Hurso	09° 36"	041° 38"	1111	15.2	2.6 (1-4)
Eror Gota	09° 33"	041° 51"	1119	20.7	3 (2-4)
Harari (Eror Oldia)	09° 19"	042 12"	1455	10	0.7(0-.5)

Means within a column followed by the same letters are not statistically different at p = 0.05. *Means of five trees , ** 0-4 score scales, where, 0=0%, 1 =1-10%, 2 =11-25%, 3 =26-50%, 4 =>50% (Seif and Hillocks, 1999).

Huanglongbing (greening) (*Liberibacter africanum*)

Huanglongbing (HLB), also called greening, is one of the most devastating diseases of citrus in the world. It is now found all over the tropical and subtropical countries of Asia and Africa. In the Philippines, it is the main reason why citrus production fell by 60% between 1961 and 1970. In Vietnam, up to 90% of the citrus trees in some areas are believed to be infected with citrus greening (Zhao, 1981).

HLB, Chinese for "Yellow shoot disease", probably originated in China, where it is given its name because of its characteristics symptom, a yellowing of some of the new shoots in the green canopy. It is caused by several species of the genus *Candidatus* consisting of phloem limited uncultured bacteria (CABI, 2007). It is a disease of rutaceous plants and transmitted by the vector psyllids *Diaphorina citri* and *Trioza erytreae* (Bové and Garnier, 1984). Under experimental conditions, both species of psyllid are able to transmit the two different forms of the HLB bacterium. It is the common needs of temperature

altitude and humidity that restrict a single vector species to one form of the bacterium in the natural environment (Coletta-Filho *et al.*, 2004).

In Africa *Candidatus liberibacter africanus* and *T. erytreae* have been reported in South Africa, Zimbabwe, Malawi, Burundi, Kenya, Somalia, Ethiopia, Cameroon and Madagascar (Saponari *et al.*, 2010). HLB has been regarded as one of the most important threats to global commercial and sustainable citrus production. As the causal agent is not available in culture, molecular techniques have been used alone to characterize the organism. (Garnier and Bové, 1983).

In South Africa, the disease was known as citrus greening because fruit from infected trees did not color up but instead remained green. However, since the disease was first described in China in 1919, the officially accepted name is Huanglongbing (Graca and Korsteń, 2004). The HLB causing bacteria have not been cultured in the laboratory and do not survive outside the host cells, making them difficult to study.

There is no cure for the infected trees, which decline and die within a few years. Further, the fruit produced by infected trees is not suitable for either the fresh market or juice processing due to the significant increase in acidity and bitter taste (Marylon *et al*, 2007). HLB can destroy citrus groves within 5 to 8 years. Apart from prevention there are no control measures currently available, causing HLB to often be described as the most destructive and serious disease of citrus.

Taxonomy and nomenclature At least three species or forms of phloem-limited bacteria have been described as causal agents of HLB (Bové and Garnier, 1994). The Asian form, *Candidatus liberibacter asiaticus* occurs throughout Asia (Garnier *et al.*, 2000). Disease symptoms for this form occur at lower elevations (360m) under low humidity and at both cool and warm temperatures (heat- tolerant) up to 35 ^{0}C (Garnier and Bove, 1996). I t is typically vectored by the Asian Citrus psylid, *Diaphorina citri kuwayama.*
The African form, *Candidatus liberibacter africanus*, is less severe, more restricted geographically, and is considered heat – sensitive (Bove, 2006). It is found in Africa, South of the Sahara, and is vectored by the African citrus psyllid, *T. erytreae* Del Guerico (Catling, 1970). *T.erytreae* is heat sensitive as well. Symptoms are produced under somewhat moist, cool conditions between 20 and 27 ^{0}C and at higher elevations (900m) (Bove and Garnier, 1994). Under experimental conditions, both species of psyllid are able to transmit the two different forms of the HLB bacterium. It is the common needs of temperature

altitude and humidity that restrict a single vector species to one form of the bacterium in the natural environment (Marylon *et al.*, 2007). In 2004 a third form was identified in Brazil; *Candidatus liberibacter americanus* (Coletta-filho *et al.*, 2005). So far, the American form is known only in Brazil. In this case, the bacterium is vectored by *Diaphorina citri*.

Symptoms The first symptom of Huanglongbing is usually the appearance of a yellow shoot on a tree. Progressive yellowing of the entire canopy follows: leaves turn pale-yellow, show symptoms of zinc or manganese deficiency, or display blotchy mottling, and are reduced in size. Blotchy mottle is the most characteristic symptom, but is not specific to Huanglongbing. Huanglongbing bacteria do not induce the xylem dysfunction and wilting. The fruits are often small, lopsided and poorly colored (hence the origin of the name greening) (Huang *et al.*, 1980) (Figure 4). The symptoms of Huanglongbing can be confused with stubborn disease (*Spiroplasma citri*), Citrus *tristeza* virus, species of *Phytophthora*, and certain nutrient deficiencies.

Figure 4. Symptoms of Huanglongbing (*Candidatus liberibacter)* on citrus leaves and fruits

Host Range and Geographic Distribution Huanglongbing is a disease of rutaceous plants. It severely affects sweet orange, mandarin and tangelo trees but many other species show more or less pronounced symptoms of the disease. Mexican lime (C. aurantifolia) is less susceptible than sweet orange and mandarin even though it is a preferred host of the vector D. citri (Bové and Garnier, 1994).

The geographical distribution of *L. asiaticum* and *L. africanum* has been studied. Only *L. asiaticum* was found in isolates from the 12 Asian countries

studied, i.e. India, Nepal, Sri Lanka, Myanmar, Vietnam, Cambodia, Malaysia, Indonesia, Thailand, the Philippines, Taiwan, Japan, the Arabian Peninsula and China. Only *L. africanum* was found in samples from South Africa and Zimbabwe (Garnier and Bové, 1996; Colleta-Filho *et al.*, 2004) (Figure 5). Both *L. asiaticum* and *L. africanum* were present in Reunion and Mauritius, sometimes co-existing in the same tree. Yemen, Burundi, Ethiopia, Cameroon, Kenya, Malawi, Rwanda and Somalia; in these countries the vector is the African psyllid *T. erytreae*.

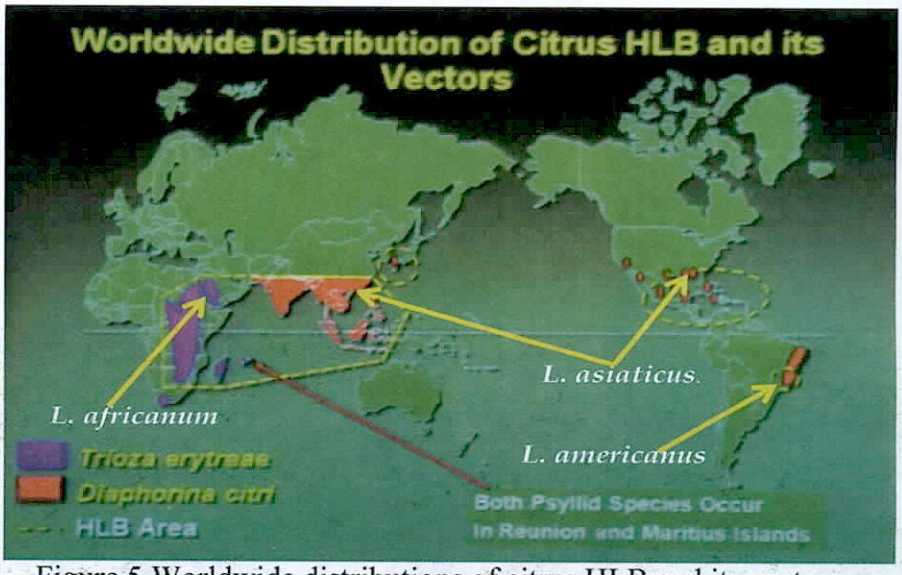

Figure 5 Worldwide distributions of citrus HLB and its vectors

Means of Dispersal and Phythosanitory significance Citrus greening is transmitted by the citrus psyllid, a small insect that sucks the sap from trees and by the vegetative propagation of cuttings and suckers from infected trees.

The major phytosanitary risk is presented by the introduction of Liberibacter-infected citrus budwood or trees into regions still free from the disease but where the psyllid vectors occur. Restriction of movement of plant material from infected to non-infected regions applies not only to citrus fruit trees but also to rutaceous ornamentals. The detection of the huanglongbing pathogens, particularly *L. asiaticus,* generally seems to follow the introduction of the vector to a new area, e.g. Brazil and Florida.

HLB Management

Biological control: Biological control of the two psyllid vectors was achieved successfully in Reunion with hymenopteran psyllid parasites: *Tamarixia radiata* introduced from India against *D. citri,* and *Tamarixia dryi*, from South Africa, against *T. erytreae* (Hoy and Nguyen, 2000). Unfortunately, biological control of the psyllids cannot be achieved in most countries because the psyllid parasites are themselves hosts for parasitic insects.

Chemical Control: Appropriate use of insecticides has resulted in good control of *T. erytreae*, the vector, in South Africa (Graça, 1991). For control of the liberibacters, injection of antibiotics and especially tetracycline into the trunk of affected sweet orange trees in South Africa has resulted in at least partial recovery of the trees. However, tetracycline is bacteriostatic not bactericidal and has to be injected repeatedly. It is also phytotoxic. Its use on a large scale might have adverse effects on the environment. For these reasons, its use has decreased in recent years. In Indonesia, a nation-wide, large-scale tetracycline injection program has failed.

Cultural Methods: In areas where the disease is not present, the most effective means to control the disease is to prevent its introduction or that of the vectors through strict quarantine measures. Inclusion of the alternative hosts in this strategy is also important (Graca and Korsten, 2004). Removal of infected branches or trees and neglected trees, use of Liberibacter-free planting material, and control of the psyllid vector are used to reduce the impact of the disease (Buitendag and von Broembsen, 1993). Some isolates of Citrus tristeza virus are reported to protect trees from HLB infection (Vuuren *et al.*, 2000).

Integrated Pest Management: The use of clean budwood and certified healthy trees is essential in preventing the disease. Budwood sources and nursery stock should be protected from psyllid infestation by screened enclosures and the use of systemic insecticides (Paul, 2008). Removing infected trees is the only way to ensure they will not serve as a source of the bacteria for psyllid acquisition and subsequent transmission. Prior to removal, the infected tree should be treated with a foliar insecticide to kill all adult psyllids feeding on that tree.
Integrated pest management strategies should focus on the following: Use of disease-free nursery trees, reduction of the inoculum by frequent disease surveys, removal of symptomatic trees, and suppression of Asian citrus psyllid populations. However, it is challenging to control any disease whose pathogen lives in the phloem.

Status of HLB in Ethiopia

Diagnoses of the HLB bacterium using PCR and identification of vectors associated with the disease in Ethiopia have been reported by different authors (Aubert *et al.*, 1988, Saponari *et al.*, 2010). However, most of the works previously conducted on the disease were based only on diagnosis and detection of the pathogen and did not address the extent of damage and distribution of the disease in the country. On the other hand, preliminary observations on different citrus trees in various parts of the country indicated symptoms similar to the disease and the presence of the vector citrus psyllids (*T. erytreae*) and its symptoms on leaves of the same citrus trees infected with the disease were also observed. This may suggest the widespread occurrence of the disease in the country. On the basis of this assumption, a study on the occurrence and distribution of Huanglongbing (Greening) disease and detection of the causal agent (*C. liberibacter*) in Ethiopia is currently being investigated by the Ethiopian Institute of Agricultural Research (EIAR). The main objectives of this study are to asses the occurrence, distribution, and extent of HLB (greening) (*C. liberibacter*) damage in major citrus growing regions of Ethiopia and to diagnose and confirm the form of HLB (greening) (*C. liberibacter)* causing bacterium in the country. The expected outputs from this study are; survey results detailing distribution and extent of damage of HLB in the country will be generated. Geographic positions of the survey areas will be recorded using the Geographic Positioning System (GPS) and the distribution of the disease in the country will be mapped. Laboratory diagnosis results confirming the type of HLB causing organism in the country will also be obtained.

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The Larger Grain Borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), an invasive pest of maize and cassava in Africa: A review

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Introduction

Grain storage is a crucial component of the post-harvest chain. From the time that man settled down and started with agriculture, storage of foodstuffs and seeds has been a natural and integral part of his strategy for survival. Grain storage is practiced by farmers, traders and governments to facilitate marketing and ensure food security. Food has to be stored from one growing season to the next, and a reserve has to be kept in the case of a bad harvest.

Crop pests cause huge amount of losses both in the field and in storage especially in the tropics where climatic conditions are favorable for their multiplication and development. The introduction of alien pests into new habitats due to the global increase of trade and transportation causes another dilemma. When a pest is carried to a new geographical area, its natural enemies that keep it in check in its aboriginal home are normally left behind. This situation, in most cases, may lead to critical complications. The greater grain borer, *Prostephanus truncatus* (Horn), is a more destructive pest of stored maize and cassava in Africa than in its native Central America (Dick, 1988), where it is said to cause sporadic damage to maize in rural stores. The apparent absence of any natural enemies or competitors has allowed populations of *P. truncatus* to expand rapidly and become the most important pest of stored maize and cassava in East and West Africa (Dick, 1988). According to Hodges *et al.* (1983), local storage practices and ideal environmental conditions together with little predation and competition from other insects have led to its becoming a very important member of a complex of pests infesting farm-stored maize cobs in parts of East and West Africa. After the accidental introduction of *P. truncatus* into Togo, which probably happened in 1981 (Harnisch and Krall, 1984), the pest spread over the whole country within 10 years (Richter and Biliwa, 1991). Haines (1991) indicated that it seems likely to invade all maize and cassava growing areas of tropical Africa, and it is the only recent example of invasion by a serious storage pest on a regional or continental scale.

In Ethiopia, the insect was given special status and quarantine was imposed against it after it was discovered in Tanzania in 1981. Many countries now impose strict quarantine measures to prevent the spread of this pest and for that reason *P. truncatus* has become one of the most notorious insect pests of stored products. Once it is introduced, the opportunity for this insect to become permanently established in the country is great.

History of *P. truncatus* in Africa

The greater grain borer is originated in Central America, where it was first identified in 1878 (www.fao.org). According to Bell and Watters (1982), the species was described by George Horn from two specimens obtained in California and was named *Dinoderus truncatus* (Horn). Lense (1898) assigned the species to the genus *Prostephanus*. The insect has been intercepted in imported foods in different countries (Israel in 1962; Iraq in 1970; Canada in 1970). Since then it went into different parts of the world, including Africa. In East Africa, it was first identified in 1980 in the Tabora region of Tanzania. Some reports, however, indicate that it presumably spread from Mexico after 1971 to East Africa. But not until a considerable population density had been reached was it identified in Tanzania in 1981. According to Dunstan and Magazini (1981), the pest was accidentally introduced into East and West Africa in the late 1970s and early 1980s, respectively. By 1983 it reached Kenya. According to Haines (1991), in 1984 it was found in Togo, presumably from a separate introduction, and it has already spread into Benin and Ghana where it was found in 1986 and 1989, respectively. It was not reported from Ethiopia until 2008 (Abraham, et al., 2008). Recently, however, EIAR (2009) reported that the Plant Quarantine Station at Moyale had reported to catch beetles in traps baited with pheromone of *P. truncatus* in April 2008; and further to early October. More recent catch reports also showed that beetles were trapped in July, October and November 2010 (Moyale Plant Quarantine Station, pers. com.). The samples were reported to be positively identified as *P. truncatus* in the International Institute of Tropical Agriculture, Biological Control Center for Africa in Benin. However, the pest was not reported to be found in any of the grain samples obtained from different stores and market places in suspected areas in the districts of Moyale, Bulo Hora and Arsi Negele. Reports indicate that except when populations are very high it is not possible to detect the pest by visual inspection (www. infonet-biovision.org).

Geographical distribution of *P. truncatus*

According to Haines (1991), *P. truncatus* is indigenous in Central America, tropical South America, and the extreme south of the USA (Arizona, California,

district of Colombia), as a major but localized pest of farm-stored maize. In Asia, it occurs in China, Hong Kong, India (restricted distribution), Philippines and Thailand; in Europe it occurs in France. In Africa, the pest is currently known to occur in Tanzania (1981), Kenya (1983), Benin (1984), Burundi (1984), Togo (1984), Guinea (1987), Ghana (1989) Burkina Faso (1991), Malawi (1991), Nigeria (1992), Rwanda (1993), Niger (1994) (Hodges, 1994 cited by Adda *et al.*, 1996), Zambia (1993), Uganda (1997), Namibia (1998), Mozambique (1999), and South Africa (1999) (www.fao.org, and infone-biovision.org) (Fig. 1). More recently its occurrence in Zimbabwe (2006/7) (Nyagwaya, et al., 2010) and in Senegal (2007) Gueye *et al.*, 2008) have been reported.

Economic importance

Huge losses in grain weight, grain quality, and nutrition, and commerce occur. The introduction of this pest in Africa has influenced the economy of several countries, especially those depending on exporting maize. Many countries now refuse to import maize from areas infested with the lager grain borer. Occurrence of the pest in a consignment of export grain implies serious financial loss for the exporter, because of disinfestation costs, a delay in discharging the grain and/or a loss of goodwill from the exporter.

Host range

In addition to maize, adults have been reported feeding on cacao beans, coffee beans, haricot beans, cowpea and groundnuts (Shires, 1977). However, successful population build up occurs only in maize and soft variety of wheat (Shires, 1977) and dried cassava (Hodges *et al.*, 1983). Yam, sorghum and wheat are also reported as secondary hosts. It is also able to breed on dead, dry wood of a range of trees. In heavy infestations, wooden storage structures may become damaged and act as reservoirs of infestation from which the new harvest may be attacked. Surveys have detected significant numbers of *P. truncatus* both in farmland and in various natural habitats, especially dry, deciduous woodland (Rees *et. al.*, 1990; Nangayo *et al.*, 1993, Tigar *et al.*, 1994). Early records also associated *P. truncatus* with various other non-food plant products, both woody and starchy, and in due course reproduction was observed on woody substrates in the laboratory and in natural forest. However, the extent to which the biology of *P. truncatus* permits it to survive and reproduce in non-agricultural environments is not known well.

Infestation and damage

Adult *P. truncatus* are good fliers and infestation may start in the matured maize crop in the field, whilst maize and cassava are drying, or once these have been dried and placed in store (Hodges et al., 1983; GASGA, 1998). Many investigators reported that *P. truncatus* does not locate stored produce by responding to volatiles from the commodity itself; initial colonizers arrive by chance (Hodges, 1994; Scholz et al., 1997a; Fadamiro *et al.*, 1998). Once even a single male has arrived and releases an aggregation pheromone signal, the stored produce is placed under increased treat (Scholz *et al.*, 1997b; Birkinshaw and Smith, 2000). Infestations by *P. truncatus* build up more slowly than those of several other important pests (Shires, 1980).

It attacks cobs and shelled maize (Hodges *et al.*, 1983), but greater damage occurs on cob than on shelled maize (Cowley *et al.*, 1980; Golob *et al.*, 1985) because kernels are more stable on the cob (Cowley *et al.*, 1980). Adults bore into maize cobs causing irregular holes (Hodges *et al.*, 1983), neat round holes (Haines, 1991), and as they tunnel from grain to grain they generate large quantities of maize dust.

Effects of infestation by adults of *P. truncatus* on cob maize were reported by Hodges and Meik (1984). Subramanyam *et al.* (1987) studied the effects of the pest feeding on shelled maize in the laboratory. Adults when fed at densities of 25, 50 or 100 on 200 maize kernels for 10-40 days did not preferentially feed on the endosperm or germ and damaged both. Fifty or 100 adults of *P. truncatus* feeding on 100 g of maize for 10-40 days caused substantial damage resulting in decreased weight and kernel germination. Kernel damage, grain weight loss and germination after 40 days of adult feeding was about 5-8, 6-8 and 68-72%, respectively. Fifty adults of *P. truncatus* when fed on 100 g of maize for 20 days at 75% r. h. caused significantly greater kernel damage and grain weight loss at 30°C than at 25°C. However, adult survival at the three temperatures was similar (Subramanyam *et al.*, 1987).

Hodges and Meik (1984) investigated initial attack and subsequent development of *P. truncatus* on maize cobs, with husk intact, at 27°C and 40, 50 and 75% r. h. The beetles showed a strong tendency to attempt infestation by first boring into the maize cob cores although they eventually gained access to the grain via the apex of the cob by walking between the grain and husk. At 50 and 75% r. h. the rate of oviposition over the first two weeks was particularly high, while at 40% r. h. the rate was more or less constant. Some F_1 generation completed their development within 32-39 days at 50% and 75% r. h. and

within 39-46 days at 40% r. h. Estimates of the population increase under each of the three moisture conditions indicated that the population increased most rapidly at 70% r. h. and was at its peak between the eighth and 12th weeks during which time grain damage and weight loss had effectively reached 100%. At 50% r. h., this stage was reached between the 12th and 16th weeks while by this time at 40% r. h. the grain weight loss was only 40% (Hodges and Meik, 1984).

Grain weight losses

Hodges *et al.* (1985) reported losses of 73.6% on fermented and 52.3% on unfermented dried cassava chips after a 4-month storage period in Tanzania. Pantenius (1988) reported a mean loss of 30.2% on stored maize six months after storage in Togo. In Tanzania, Keil (1988) reported maize losses of up to 60% after nine months of storage, and Hodges *et al.* (1983) reported 34% after 3-6 months farm storage with an average loss of 8.7%. When compared with the damage caused by the more usual storage pests (e.g. *Sitophilus zeamais* and *S. oryzae* and *Sitotroga cerealella*) under similar circumstances, *P. truncatus* is obviously a very serious pest. During an entire storage season in Zambia, Kenya and Malawi maize losses due to these other pests were, respectively, 2-6, 3-5 and 2-5% (Hodges *et al.*, 1983). Alarming losses of stored maize were reported in East and West Africa (Golob, 1984; Hodges, 1984; Pantenius, 1987) with dry weigh losses of up to 45% after 8 months of storage.

Recognition and identification

P. truncatus adults are 3-4.5 mm long, dark brown in color and are cylindrical in body shape. When reviewed from above the rear of the insect is squared shaped. The thorax bears rows of teeth on its upper front edge and the head is turned down underneath the thorax so that it cannot be seen from above. The antenna is 10-segmented with a large, loose three-segmented club.

The three bostrichids associated with stored produce, *P. truncatus*, *Rhyzopertha dominica* and *Dinoderus* spp., are morphologically very similar and difficult to distinguish from one another. The cylindrical body shape, teeth on the thorax and the deflexed head are also characteristic of these grain feeding insects in the family Bostrichidae. In *P. truncatus* the end of the wing covers are flattened and this sloping region (declivity) has two curved ridges (carinae) at the tips (GASGA, 1998). Haines (1991) indicated that in most species of *Dinoderus* there is a pair of slight depressions (foveae) at the base of the pronotum and the scutellum is transverse, being about twice as wide as it is long. The elytra hairs are short and erect. The declivity is strongly convex and lacks any

ornamentation or ridges. In *R. dominica*, the declivity of the elytra is gently convex.

Biology and ecology

Adult females lay eggs in chamber bored at right angles to the main tunnels. Egg-laying on stabilized grain, like that on the maize cob, is more productive than on loose shelled grain as not only is the oviposition period longer, equal in length to the life of the female, but eggs are laid at a greater rate (Haines, 1991). The females lay batches of 4-8 eggs, and on hatching the larvae tunnel into the grain within which the eggs are laid (Li, 1988).

Larvae hatch from the eggs after about three days at 27°C (Haines, 1991) 3-7 days (GASGA, 1998) and seem to thrive on the dust produced by boring adults. Large numbers of larvae are found developing, for example, in dust at the base of dense laboratory cultures, where they also pupate (Haines, 1991).

The larvae are white, parallel-sided, fleshy and sparsely covered with hairs and have three pairs of legs. They develop within the grain or in the flour that accumulates by the feeding action of the adults. Pupation takes place inside the food source. The life-cycle takes 25-26 days at optimum conditions (30°C and 70% r. h. and 13% seed mc). Under cooler or drier conditions it takes longer (www. infonet-biovision.org). The wide range of temperature and r. h. at which oviposition and development can occur favor the establishment of *P. truncatus* in tropical and subtropical regions of the world where maize is grown and stored (Bell and Watters, 1982).

The life-cycle has been investigated at a range of temperature and humidity conditions (Shire, 1979; 1980; Bell and Watters, 1982; Hodges and Meik, 1984). Shires (1979) has reported on its life-history and development at 22-35°C and 50-80% r. h. reared on ground maize. He found that development from hatching to adults was possible at every one combination of the 24 combinations of 6 temperatures and 4 relative humidities used, and the period required was shortest at 32°C and 80% r. h.. Rate of development was slower at 35°C than 32°c, being similar to that observed for 25-27°C. At 22°C the rate of development was apparently slower. Below 70% r. h. at all temperatures the developmental period increased markedly, but at 80% r. h. it was sometimes shorter and sometimes longer than at 70%. In general, mortality was low in the 27-23°C and 70-80% r. h. zone, but tended to increase at lower humidities and more extreme temperatures, especially 35°C (Shires, 1979). Bell and Watters (1982) studied over a wider range of temperature (12-40°C) and r. h. (30-90%),

and reported that temperature, relative humidity, food density and maize cultivar influenced oviposition, development and intrinsic rateof increase.of *P. truncatus*. The lower and upper limits for complete development were 25 and 32°C at 40% r. h.; 18 and 37°C at 70% r. h.; and 20 and 32°C at 90% r. h. The shortest developmental periods were 24.1 days in whole kernel and 25.4 days in ground maize of different varieties, respectively at 32°C and 70% r. h. and 32°C and 80% r. h. (Bell and Watters, 1982).

According to Bell and Watters (1982), *P. truncatus* laid 430 eggs per female in blocks of maize consisting of 6-cemented kernels during 22 weeks compared with 205 eggs per female in ground maize during 15 weeks, and 36 eggs in loose maize kernels during 4 weeks. Viable eggs were laid at 18°C and 70% r. h. and 32°C and 70-80% r. h.

According to Haines (1991), development of the larvae through to adult at the optimum, 32°C and 80% r. h., took only 27 days on a maize grain diet. Humidity within the range 50-80% r. h., does not greatly affect the development period or mortality, at 32°C, a drop in r. h. from 80% to 50% (giving maize with an equilibrium moisture content of approximately 10.5%) extended the mean development period by just six days and increased the mean mortality by only 13.3%. This tolerance of dry conditions has been confirmed during field studies in Tanzania in which maize at 9% moisture content was heavily infested. The ability of *P. truncatus* to develop in grain at low moisture may be one reason for its success. Under such conditions many other storage pests are unable to increase in number. For example, *Sitophilus oryzae* a species occurring in the same ecological niche needs a grain moisture of at least 10.5% to be able to develop. It would appear that this pest develops more rapidly on maize grain than on cassava since, at least at 27°C and 70% r. h. the respective development periods were 32.5 days and 40 days. Estimates for the intrinsic rate of increase (r) of *P. truncatus* under ideal conditions of temperature and humidity on maize cobs or stabilized maize grain are in the order of 0.7-0.8/week. This is similar to the rate of increase reported for *Tribolium castaneum* under comparable physical conditions (Haines, 1991). The pest proved to be highly tolerant to low moisture contents in grain. Heavy infestations in maize at a moisture content as low as 9% were reported (Hodges et al., 1983).

Subramanyam, *et al.* (1985) recognized three larval instars of *P. truncatus* in rearings at 25°C and 75% r. h., based on the greatest distance between the ventrally sclerotized lateral structures of the frontoclypeus. Bell and Watters

(1982) found the overall larval period for most individuals to be about 17 days at 30°C and 70% r. h. During the 17 days head capsules fell into three discrete size ranges suggesting three instars: The duration of the first, second and third instars was 4-5, 5-6 and 6-7 days, respectively.

Shires (1980) found at 32°C and 80% r. h. that mean egg, larval and pupal development period of *P. truncatus* were 4.86 (range 4-7), 25.4 (range 17-35) and 5.16 (range 3-7) days, respectively. After a pre-oviposition period of 5-10 days, female adults laid most eggs at 15-20 days old and some continued to lay eggs for a further 70-80 days. Mean total egg production was 50 eggs per female and the maximum number of eggs laid by one female was 145. In any 5-day period the greatest number of eggs laid by a single female was 33 (about 6.6 per day). On average 68% of all eggs were found inside damaged grains, although this varied considerably among females (range 23.9-100%). Mean adult longevity was 44.7 days for males and 61.1 days for females but these were not significantly different due to high variability in the data. The maximum longevity of males and females was very similar, being 107.5 and 112.5 days, respectively (Shires, 1980).

Flight behavior

Tigar *et al.* (1993) studied the relationship between time of day and catch of *P. truncatus* in pheromone baited traps and found that the insect exhibited a bimodal pattern of flight activity with a major peak in the evening between 18:00 and 21:00 h, and a smaller peak in the morning between 07:00 and 09:00 h. The effective life of the pheromone bait was also investigated over 33 days. The highest numbers of *P. truncatus* were caught during the first eight days and the majority of the beetles were caught within 14 days. Catches then showed a steady decline. Captures of the predatory histrid *Teretrius* (formerly *Teretriosoma*) *nigrescens* were much lower than those of *P. truncatus* and showed fluctuations which did not appear related to numbers of its prey. Environmental factors such as rainfall, temperature, wind and trap positioning appeared to influence results, especially when considered over a short time scale.

Flight is an important part of both its biology and the knowledge needed for effective control. Fadamiro and Wyatt (1995) studied the influence of time of day, temperature, relative humidity and starvation on flight initiation by *P. truncatus* in the laboratory, and reported that time of day and temperature have major influences on flight activity in *P. truncatus*. In addition, starvation may also be important in determining the likelihood of flight initiation. Flight

occurred throughout the 12 h photophase but peaked at 2-0 h before darkness. This period corresponded to the tail end of the photophase in the laboratory or dusk in the field. Temperature exerted a significant effect on flight. The frequency of flight take-off increased with temperature over the range 20-30°C but declined sharply at 35°C. Flight activity increased with starvation up to a maximum at 2 days after which it began to decline. Adda *et al.* (1996) reviewed that onset of the rainy season is associated with maximum levels of flight activity in long-term monitoring studies in East Africa.

Trapping methods

Following the original Tanzanian outbreak, a trap for monitoring the spread of the beetle was developed at the Overseas Development Natural Resources Institute (ODNRI) (Hodges *et. al.*, 1984; Hodges, 1986) and has been used to assist the monitoring of the distribution of the beetle in countries where outbreaks have subsequently occurred. Commercial production of the trap is now carried out by Biological Control System Ltd (BIOCON), now Agrisense BCS Ltd. (Dendy *et al.*, 1991). Male *P. truncatus* beetles produce an aggregation pheromone, the major component of which has been identified as 1-methylethyl(E)-2-methyl-2-pentenoate. This was given the trivial name Trunc-call 1 (T1) and is currently used as lure in the ODNRI trap. A second minor component has later been identified as 1-methylethyl(E,E)-2,4-dimethyl-2,4-heptadienoate (Trunc-call 2, T2) (Hodges *et al.*, 1984; Dendy *et al.*, 1991). Traps baited with lures containing both pheromone components have been tested in maize stores in Tanzania where it was found that mixtures of T1 and T2 caught ten times as many beetles (Dendy *et al.*, 1989) more beetles (Dendy *et al.*, 1991) than T1 alone. Dendy *et al.* (1989) recommended that pheromone lures could be used to trap flying *P. truncatus* in fields of growing maize. Dendy *et al.* (1991) found that T1 was released faster from the vials than T2, but at least 19% of each component remained after two weeks exposure. However, it was recommended that lures used in store traps should be replaced every two weeks.

Cardboard refuge traps treated with insecticides and baited with the male-produced aggregation pheromone of *P. truncatus* have been used extensively in Africa to monitor the distribution of the beetle. The pheromone bait is also effective with traps of other designs (Haines, 1991).

Flight traps such as funnel, delta or wing traps baited with pheromone are considered the best for monitoring the greater grain borer. The traps are suspended about 1-2 m from the ground outside the store or standing maize

crop; at least 100 m away in order to avoid attracting the pest to these food sources. Small populations already present feeding on maize/cassava in a store cannot be detected by pheromone traps because the pest does not react to the pheromone until dispersing from its food source. Only when the population has increased to an extent whereby the infestation is obvious and the beetles are starting to disperse will the traps catch beetles. Hence, the only means of assessing infestations in store is by manual sampling of the produce. Although the traps and pheromones are available commercially, they are expensive and not easy to get (www.infonet-biovison.org). Moreover, pheromone traps are time consuming to deploy so their long-term use by extension services in developing countries is unlikely to be sustainable.

GASGA (1998) indicated that in monitoring programs, traps should be placed in a wide range of locations including those away from stores or maize-producing areas since substantial catches of *P. truncatus* have been obtained uninhabited, uncultivated areas.

Control methods

Cultural control

Timely harvesting, proper drying, storing clean (free of infestation) and shelled maize in a clean and suitable container, locating stores far from the field (or any source of infestation to avoid cross infestation) are some of the important cultural practices recommended for the control of storage pests. Studies in Benin have shown that maize harvested three weeks after physiological maturity gave better economic returns when stored for eight months than maize harvested one or seven weeks after physiological maturity (Borgemeister *et al.*, 1998). As *P. truncatus* has great difficulty in clinging to loose individual grains (Cowley *et. al.*, 1980) it is a much more serious pest of cob maize than shelled maize. Golob *et al.* (1985) confirmed that the beetle develops much less effectively on loose grain than on the maize cobs, and suggested that effective control could, therefore, be facilitated if maize were to be stored after shelling rather than on the cob. If cobs are to be stored then they should be with tight sheathing leaves (Meikle *et al.*, 2002; Borgemeister, *et al.*, 2003). Giga and Canhao (1993) reported that *S. zeamais* would out-compete *P. truncatus* on loose maize at 25°C.

Storage of cobs in open structures predisposes them towards heavy infestation whether they are treated with insecticides or not. The larger grain borer easily attacks grains stored in gunny bags or guards. Moreover, this pest also damages guards. The most suitable containers are those that can be sealed such as

metallic containers, old oil drums or mudded cribs or baskets. They provided a very effective barrier to pest attack and can be used provided the stock is sufficiently dried so that ventilation is not required. Use of brick stones and preferably iron sheet roof are recommended to construct the granaries; wood and grass would encourage breeding and multiplication of the larger grain borer (www.infonet-biovision.org).

Grain must be dry (moisture content of less than 12%) if it is stored in impermeable containers to avoid anaerobic fermentation and consequent rotting (Golob and Hanks, 1990), although *P. truncatus* is a serious pest even on maize with very low moisture content (9%) (Hodges *et al.*, 1983). Well dried kernels are too hard to bite through with the teeth. Heat used for drying the produce will also kill larvae and chase away adults of insect storage pests. Care should be taken to avoid overheating since excessive heat can damage seed or grains. Temperatures should not exceed 35°C for beans, 43°C for oilseeds and 60°C for cereals. Seed can be spread out in the sun on a hard clean surface to dry for several days in dry weather. The thickness of the layers of cobs, panicles, pods or grains must not exceed 5 cm, and the seed must be turned regularly in order to ensure good and even aeration. In the evening, the produce must be put in a pile and covered (www.infonet-biovision.org)

In the case of cassava, the roots should be left in the ground for as long as possible to reduce the storage period in order to minimise losses. After harvest, it should be sun dried and immediately transferred to sealed containers.

Insecticidal plants and other additives

Golob and Hanks (1990) evaluated several botanicals such as *Melia azedarach* leaf powder, pyrethrum crude aqueous extract, *Azadirachta indica* leaf powder and washed sand and ashes from paddy husk or wood. Paddy husk ash at 5% provided good protection when applied to maize grain. Wood ash was effective when admixed at 30% by weight, sufficient to completely cover the grain. Sand was also effective when applied at 20% by volume.

Among several botanicals tested (castor beans, neem seed, neem oil, pyrethrum flower and velvet leaf) pyrethrum flower powder at 0.5% (w/w) was reported to be highly effective (Stroll, 2003). Makundi (1991) found pyrethrum marc containing 0.4% synergized and antioxidized pyrethrum at 5 and 10 ppm resulted in 96.1 and 100% mortality of *P. truncatus*. The higher level was effective for periods exceeding 12 weeks.

Using plant material in the form of slurry has given better results than plant powders. The slurry can be prepared by weighing out powder into 150 ml containers and adding sufficient water to give a 10% concentration (w/w), and stirring until a smooth paste is obtained. Then, the grain is poured into prepared slurries and stirred with a rod until all grains are coated (Stoll, 2003). A mixture of neem and pyrethrum known as ("Nimpyr") (1.5-2 kg of neem kernel powder mixed with 0.5-1 kg pyrethrum flower powder per 100 kg grain) seems as a better option to protect stored maize from mixed infestations. Trials in Tanzania showed much lower grain damage in maize treated with "Nimpyr" (0.5 - 6% kernel infested) compared to untreated maize (17% to over 90%) six months after treatment (www.infonet-biovision.org).

Treatment of grain with a mixture of 2 kg of ash with 1 tablespoon of chilli powder at the ratio of 1 part ash/chilli mixture and 4 parts of grain is reported to be effective against the greater grain borer (Borgemeister *et al*, 2003). Diatomite (diatomaceous earth) at 1 kg bag^{-1} of grain) or laterite (common red soil) when admixed with grain was found to provide effective protection from *P. truncatus* (www.infonet-biovision.org).

Biological control

Natural enemies

Little is known about the relationship between *P. truncatus* and other organisms. Haines (1991) reported that in Tanzania large numbers of *Anisopteromalus calandrae* (Howard) were associated with *P. truncatus* when relatively few of the other possible hosts were present. Helbig (1998) studied two regularly observed parasitoids in farm-stores, *Anisopteromalus calandrae* and *Theocolax elegans*, for their relationship with *P. truncatus* and found that correlation coefficients for numbers of both parasitoids and *P. truncatus* were mainly negative and very close to zero, but positive and greater in value for the parasitoids and *S. zeamais*. In glass jar trails carried out with *A. calandrae* and *T. elegans* on loose maize it was observed that *A. calandrae* reduced numbers of *P. truncatus* by 70.1% in the single species culture after eight weeks, whereas *T. elegans* had no impact. In double species culture *A. calandrae* had an effect on both populations; *P. truncatus* was reduced by 61.3% and *S. zeamais* by 22.5%. *T. elegans* had an influence only on *S. zeamais* (Helbig, 1998).

The hister beetle *Teretrius (*formerly *Teretriosoma) nigrescens* Lewis (Coleoptera: Histeridae) was identified as the most effective natural antagonist of *P. truncatus* in Mexico and Central America. It was first described in 1891

by Lewis. It feeds on the eggs and larvae and sometimes even on adults. Both adults and larvae of *T. nigrescens* were effective predators of *P. truncatus* (Rees, 1985). At 27°C and 70% r. h. development from oviposition to adult emergence took about eight weeks. At 30°C and 75% r. h. development took less than 50 days. Eggs hatched in 7 days at 26°C. In 24 h at 27°C and 70% r. h. *T. nigrescens* adults and larvae, respectively, consumed on average up to 1.7 and 3.5 *P. truncatus* larvae. After seven weeks, 10 *T. nigrescens* adults prevented populations of 25, 30, 50, 75 and 100 *P. truncatus* from increasing, while controls increased at least 10-fold. Grain moisture contents of between of 8.5-14% had little effect on predatory efficiency (Rees, 1985). According to GASGA (1998), to complete development the larva of *T. nigrescens* consumes up to 60 prey item. In absence of live food, adults are able to survive, but not breed, for up to a year by scavenging on grain debris and dead insects.

Richter *et al.* (1998) indicated that in agreement with all African countries, represented by the OAU, and all concerned international institutions and experts, it was decided to recommend the introduction of *T. nigrescens* into Africa as a bio-control agent for *P. truncatus* (Boye et. al., 1992). Following this decision the first release of the predator took place under the responsibility of Togolese authorities in southern Togo in the beginning of 1991 (Richter *et al.*, 1998; Helbig, 1995). The predator beetle has been released in Benin, Ghana, Guinea-Conacry, Kenya (1992), Malawi, Tanzania, Tog (1991) and Zambia; and it became well established and spread in most countries (www/infonet-biovisio.org).

Helbig and Schulz (1996) studied the potential of the predator *T. nigrescens* for the control of *P. truncatus* on dried cassava chips and cassava wood, and found that on both substrates, the development of the population of the pest was controlled effectively. After 12 weeks, with a predator to prey relationship of 5:100, the population of the pest was reduced by 64.4% on dried cassava chips and by 76.5% on wood of *M. esculenta*. Christian *et al.* (1997) reported that studies conducted between 1992 and 1997 in southern Benin to investigate the establishment, spread and impact of the predator showed a rapid establishment and spread of the predator throughout the region. A considerable reduction of *P. truncatus* infestation and decreasing losses of maize coinciding with the increasing presence of *T. nigrescens* was reported. Richter *et al.* (1998) reported that after the first release of the predator in Togo the number of *P. truncatus* was reduced by 56.4% in stores with presence of the predator as compared to the control after eight months of storage in 1990/91. Damage and losses of stored maize cobs were 40.7% smaller than without the predator. Richter *et al.*

(1997) investigated traditional maize stores in southern Togo from 1988 to 1992 in order to compare losses and damage to stored cobs and infestation by insect pests before and after the release of *T. nigrescens*. It was found that the infestation of *P. truncatus* in the stores decreased after release of the predator in 1991. Before the population of the pest was 4300 adults on average per 100 cobs after eight months of storage. In the years following release, there were only 296 adults per 100 cobs when *T. nigrescens* was present in stores, a reduction of 93.1%. Damage to grains was 21.2% in the presence of *T. nigrescens* compared to 62.6% without the predator, and losses were reduced by an average of 81.2% (Richter *et al.*, 1997).

Rees (1991) investigated the effects of *T. nigrescens* on three species of bostrichids associated with stored food products: namely *P. truncatus*, *Dinoderus minutus*, *Rhyzopertha dominica* in order to determine the potential host range of the predator, information on which is required to asses its safety and potential ecological impact prior to its possible release into Africa. The results indicated that the population of *P. truncatus*, *D. minutus* and *R. dominica* was reduced by 83, 91 and 36% respectively when five predators were added to 40 adults of each species at 27°C and 70% r. h. Weight loss to maize caused by the bostrichids was also reduced by 59, 65 and 28%, respectively, after eight weeks. To mass-rear *T. nigrescens* prior to release for the control of *P. truncatus*, the production of large number of *P. truncatus* as prey is required. This could raise the fear of the consequences of their accidental escape from the rearing facilities which, for operational reasons, have been placed in an area currently uninfested with this pest. The use of alternative prey species such as *R. dominica* may alleviate these fears (Rees, 1991).

However, despite the successful introductions of the predator in the different countries, there are still regular outbreaks of *P. truncatus* and farmers are still suffering losses (www/infonet-biovisio.org). Niels and Meikle (2003) also reported that the predator can suppress both *P. truncatus* and *S. zeamais*. But concluded that classical biological control with *T. nigrescens* is not likely to become successful, mainly due to the predator's intra-specific density dependence and its low population growth rate compared with its prey. They recommended further research on integrated management of *P. truncatus* taking into account farmers as an active agent managing the store.

Nevertheless it is believed that the predator has a role to play in the management of the larger grain borer, as it is able to reduce the density of the

pest. Rees (1987) reported that selective predation of *P. truncatus* by *T. nigrescens* did not encourage significant increases in population of *S. zeamais* or *T. castaneum*.

Entomopathogens

Kassa *et al.* (2002) assessed the efficacy of 13 isolates of entomopathogenic fungi belonging to *Beauveria*, *Metarhizium* or *Paecilomyces* spp. against *S. zeamais* and *P. truncatus* using a total immersion bioassay technique in the laboratory. All isolates tested were virulent to *P. truncatus* (98-100% mortality, and median survival time (MST) ranged from 2.85-4.05 days). *Metarhizium anisopliae* and *B. bassiana* were also virulent to *S. zeamais* (92-100% mortality, MST ranged from 3.58-6.28 days). *P. truncatus* proved more susceptible to the entomopathogenic fungi tested than *S. zeamais*. One *M. anisopliae* (PPRC-EE) and three *B. bassiana* isolates (PPRC-HH, PPRC-9609 and PPRC-9614) were selected for further study and dose-mortality relationships assessed on *S. zeamais*. *M. anisopliae* (PPRC-EE) showed the lowest LC 50 followed by *B. bassiana* PPRC-HH. PPRC-9609 and PPRC-9614 showed slight differences in LC 50 but not at LC 90. The results revealed the higher potency of *M. anisopliae* as compared with the *B. bassiana* isolates tested. The study suggests that the use of entomopathogenic fungi may hold promise as an alternative method to control pests of stored-products in Ethiopia.

Quarantine control

Reports indicate that *P. truncatus* was first recorded in the border regions and in cities rather than in the major maize producing areas (Bosque-Perez *et al.*, 1991; Adda *et al.*; 1996). From this Adda *et al.* (1996) suggested that initial invasion of the pest may be primarily through movement of contaminated commodities rather than to active migration of the insects. Hence, improved between and within-country quarantine programs combined with regular monitoring, may therefore, prevent further introductions or restrict spread of infestations. Farmers should learn how to scout for the pest and take action when a need is detected.

Chemical control

Preliminary field trials undertaken in the Tabor region of Tanzania with locally available dilute insecticide dusts indicated that pirimiphos-methyl might provide adequate protection of loose maize grain for six months (Golob *et al.*, 1983). They also suggested that shelled maize be treated with 0.5% w/w permethrin dust applied at 3 ppm.

Golob *et al.* (1985) treated adults of *P. truncatus* in the laboratory with permethrin, delthamethrin, pirimiphos-methyl, malathion, fenvalerate and chlorpyrifos-methyl, by topical application, by exposure to treated filter papers, and by exposure to maize grain treated with dilute dust formulations. Field trials were also carried out in Tanzania in a large wire mesh crib to compare the protection afforded to maize grain stored in small Hessian bags with that of cobs without husks stored in wire mesh compartments. The superiority of the synthetic pyrethroids over the organophosphorus compounds was clearly demonstrated in all the experiments except that in which insects were exposed to treated filter papers, when the observations were not conclusive. In the field trial, loose grain was protected more effectively than cobs; permethrin dust applied at 2.5 ppm resulted in only 4% damage to loose grain in a storage period of 10 months. The application of 50 g of 5% permethrin dust to a sack of maize grain (90 kg) has become the basis of a series of recommendations for on-farm storage of maize in *P. truncatus* affected areas of Tanzania (Golob and Hanks, 1990).

Other workers also reported that *P. truncatus* is not well controlled by organophosphate insecticides such as malathion or pirimiphos-methyl, but can be effectively controlled by permethrin and other synthetic pyrethroids (McFarlane, 1988 cited by Giga and Canhao, 1991). Giga and Canhao (1991) found *S. zeamais* to be less susceptible to pyrethroids (permethrin and delthamethrin) than *P. truncatus*. Similarly other stored product coleopterans are better controlled by the organophosphates. Hence, a cocktail of permethrin and pirimiphos-methyl applied at 3.3 and 17.7 ppm, respectively, is recommended in East Africa (Golob, 1988 cited by Giga and Canhao, 1991). Delthamethrin, unlike permethrin, is more effective against *S. zeamais* and is recommended for use in West Africa (Krall, 1987 cited by Giga and Canhao, 1991).

The application of residual sprays to granaries is an integral part of pest control. McFarlane (1988) drew attention to the need for farm-store disinfestations to control *P. truncatus* in wooden granaries and cribs into which the insect may penetrate and maintain reservoir population. Traditional small farm granaries are also capable of being damaged by the insect. The persistence of permethrin (e.c.) and delthamethrin (e.c. and s.c.) applied at dose rates ranging from 0.05 to 0.5 a. i. m^2 to glass, jute or plywood panels, or blocks of mud were compared using *P. truncatus* and *S. zeamais* (Giga and Canhao, 1991). Results showed that effectiveness of the treatments were influenced by the type of surface, the insecticide, its concentration and the age of deposits. The treated surfaces were

bioassayed up to 18 weeks after initial treatment. Delthamethrin was the most effective treatment on all surfaces against both species.

Insecticidal treatments were found to be more effective when applied to shelled grain than cobs (Golob *et al.*, 1985). However, according to Golob and Hanks (1990), when farmers switched from storing maize on the cob to storing loose maize the importance of infestation by *Sitophilus* spp. increased. Moreover, the need to shell the entire maize harvest simultaneously is a tedious and time consuming occupation. Hence, Golob and Hanks (1990) studied the effectiveness of applying an insecticide spray to the external surface of the cobs with husks intact as a means of protecting grain. Results showed that protection was not as effective as the protection afforded to insecticide-treated grain. However, in simulated farm-stores excellent protection was obtained either by applying permethrin as a dilute dust to grain or applying it as a spray to cobs with sheathing leaves intact. Treatment of maize cobs by spraying may provide the small scale farmer with a viable and more traditionally compatible alternative to the currently recommended practice of shelling maize and treating it with a dilute insecticide dust (Golob and Hanks, 1990).

Richter *et al.* (1998) evaluated dust formulated insecticides (pirimiphos-methyl, delthamethrin and permethrin) in traditional maize stores in Togo. The insecticides were applied in organophosphorus-pyrethroid combinations. Delthamethrin was also applied as a single product. Treatments of delthamethrin alone or in combination with pirimiphos-methyl were equally effective against *P. truncatus*, whereas permethrin with pirimiphos-methyl was less effective. *S. zeamais* was not controlled satisfactorily with any of the treatments (Richter *et al.*, 1998). Insecticide must be applied as a prophylactic measure to prevent ingress of adults rather than as a remedial treatment performed to eradicate an existing population (Golob and Hanks, 1990).

Genetic control

Meike *et al.* (1998) evaluated maize varietal characteristics in the field and in the laboratory for their efficacy in providing resistance to *P. truncatus* and *S. zeamais*, and reported that resistance appeared to be associated more with the husk cover than with the grain. Higher yielding varieties, even with hard flinty kernels, tended to suffer high *P. truncatus* damage, possibly due to the quality of the husk cover. Varietal susceptibility to *S. zeamais* did not appear to be associated with husk cover. Most damage by storage pests occurred later in the season, and damage was most strongly associated with *P. truncatus* density. An ideal maize breeding programme should include the development of maize

varieties able to resist insect attack for a long storage season, in addition to varieties with a high yield (Meike *et al.*, 1998).

Integrated pest management (IPM)

IPM is defined as a comprehensive, systematic approach to commodity protection that emphasizes increased information for improved decision making in order to reduce purchased inputs and minimize social, economic and environmental consequences. The IPM concept emphasizes the integration of disciplines and control measures including biological enemies, cultural management, sanitation, proper temperature utilization and pesticides into a total management system aimed at the prevention of pests from reaching damaging levels. From an economic and ecological standpoint, IPM is based on the economic threshold (ET) concept; it implies that management action is taken only when potential losses due to pest infestation exceed costs of available control strategies. IPM will reduce the use of pesticides because control measures will be used only when sampling indicates that insect densities have exceeded the ET. Further reductions of chemical control can be achieved by replacing pesticides with biological and physical control methods.

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Woolly apple aphid, *Eriosoma lanigerum* Hausmann, (Homoptera: Aphididae) an Introduced Pest on Apple an Introduced Crop

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Introduction

The woolly apple aphid was recorded more than two decades ago on several introduced apple cultivars at Holetta research center and latter at Tseday farm, the first apple orchard in the country. Until very recently the insect has been checked using insecticides such as by spraying Pirimiphos methyl and Pirimicarb. But, in 2008/09 heavy infestation was recorded particularly in rootstocks production plots at Holetta. In these plots the root system and the trunk below the grafting point were found heavily infested with the aphid. This resulted in rotten trunk and extensive galling in the root system. This required chemical control of campaign proportion that had to be carried out for three subsequent weeks' using Chlorpyriphos. This significantly reduced the infestation and recovery of damaged seedlings was observed. But, it did not last long and ramification of root galling was observed due to the increased in aphid population in the soil. This forced the temperate fruits research program to completely destroy the raised seedlings, which was more than 1500, using roundup, a non-selective herbicide.

The causes for this happening could be several, but the most important one was the change of rootstock from the slow growing MM106 to another obtained from Guraghe zone called Agena local. The latter rootstock grows faster and allowed the production of more grafted seedlings in a season than was possible with the MM106. It however was found to be extremely susceptible to the WAA. The problem was also observed in areas where seedlings grafted on this rootstock were distributed thus requiring the use of soil applied chemicals to check the spread and in some cases decisions were made to uproot and destroy the growing seedlings. Following this a countrywide survey was made and the aphid was found in all the places visited especially on seedlings grafted on unknown rootstocks. On the other hand, seedlings grafted on the authenticated rootstock MM106 were found to be infested lightly on their aerial parts only. What these indicate are that the wooly apple aphid has become an invasive pest

of apple by spreading along with the crop to many places in the highlands of Ethiopia.

Woolly apple aphid, *Eriosoma lanigerum* Hausmann

The aphid is native to North America. It is a key pest of apple and is well spread in almost all apple growing areas of the world (Thakur and Dogra, 1980; Mols and Boers, 2001 and Nicholas et al., 2005). The aphid inhabits both the aboveground (trunks and branches) and underground parts (roots) of an apple tree. It sucks sap from aerial as well as subterranean parts of the apple tree and induces hypertrophic galls on the roots and limbs of apple trees which hinder the normal growth of the plants (Brown and Schmitt, 1990 and Nicholas et al., 2005).

Subterranean aphid colonies cause the most damage because roots of infested trees have large and abnormal swellings. Continued feeding can kill roots and cause reduced growth or even death of young trees (Nicholas et al., 2005) and consequently affects the yield potential (Brown et al., 1995). Fitzgibbon (1996) reported that high levels of aphid infestation had a significant, negative effect on tree height, total leaf number and total leaf area. He confirmed this both in a laboratory and field experiments on non-bearing Granny Smith trees. Trees were not affected in the first year of the field study; however, highly infested trees tended to break dormancy later and/or died in the second year.

The wooly apple aphid is distinguished in the field by its production of white, woolly masses, consisting of a wax covering secreted by epithelial cells. The wax coating serves multiple purposes for the aphid colony, including preventing the aphids from being coated in honeydew that may lead to fungal attack, defense against some natural enemies, and as a protectant against UV and solar radiation. Some protection against contact pesticides may be afforded by the hydrophobic nature of the wax, although the degree to which this may occur is unknown (reviewed by Short, 2003).

Regarding their choice of feeding niche, woolly apple aphids are attracted to sunken areas caused by the disease perennial canker. Galls caused by feeding of aphids are re-infection sites for the causal fungus of perennial canker, *Cryptosporiopsis perennans*. These galls are more sensitive to low temperatures than normal bark tissue and rupture at about 0°F or colder, providing an entry site for the fungus, continuing the perennial nature of the canker (http://jenny.tfrec.wsu.edu/opm/displayspecies.php?pn=410, accessed in December 2012).

The original primary (or overwintering) host of the woolly apple aphid is American elm. In areas where this species of elm occurs, elm is the overwintering host, and apple is one of several summer (or alternate) hosts. On elm, the aphids overwinter in the egg stage. However, this aphid has adapted to live and reproduce on apple year round in most fruit growing areas of the world (where the American elm does not occur), including the western United States. There is evidence that sexual reproduction occurs on apple in New Zealand, but the importance of this has not been established (http://jenny.tfrec.wsu.edu/opm/displayspecies.php?pn=410, accessed in December 2012).

In North America woolly apple aphid is not a serious pest because of the combined effects of low winter temperature, which reduces the over-wintering population, presence of parasitoid and predator complex and application of pesticides targeting other important insect pests of apple (Beers et al. 1993). Beers et al. (1993) reported that outbreaks of the aphid in North America are blamed on pesticides that disrupted biological control.

Wooly apple aphid life stages

The egg stage is not known to occur in many places in apple orchards but there is evidence that sexual reproduction occurs on apple in New Zealand. Shortly after birth, the nymph is salmon colored, and lacks the woolly coating. This stage is known as the crawler. The waxy filaments begin to form after the aphid settles to feed. There are four nymphal instars, averaging 0.64, 0.67, 1.2, and 1.3 mm in length. Eyes are dark brown to black (no oceli). The cornicles are circular, and only slightly elevated from the surface of the abdomen. The adult is reddish brown to purple. The actual color, however, is usually concealed beneath a white, cotton-like substance secreted from the aphid's abdomen. This characteristic makes this aphid species easy to distinguish from other aphid species occurring on apple (http://jenny.tfrec.wsu.edu/opm/displayspecies.php?pn=410, accessed in December 2012).

Population fluctuation of wooly apple aphid

Seasonal population fluctuations of this pest and its natural enemies have been studied in different parts of the world (Ismail et al., 1986; Brown and Schmitt, 1994; Asante, 1999). Population of woolly apple aphid is regulated to a great extent by a number of factors including natural enemies and weather (Asante, 1999). A two year study of the spatial distribution and seasonal increase of aphid colonies showed that colonies were not equally distributed throughout the tree. A

marked increase in the number of colonies was found in the upper stratum of the tree, which was evident from the onset of infestation and continued throughout the season. A greater than expected number of colonies were found in the southern aspect of the tree. Populations reached a seasonal peak in the early autumn (March) (Asante, 1999). Studies using sticky barrier traps throughout the tree showed that there were no seasonal migrations of aphids between the roots and canopy. Trap catches showed similar trends to the colony numbers throughout the season, with a seasonal peak in late autumn (FebruarylMarch) (Fitzgibbon, 1996).

Control of wooly apple aphid

Commercial control of woolly apple aphid has relied on resistant rootstocks and chemicals since the early 1900s (Nicholas et al., 2005) and to a lesser extent, with a parasitic wasp, Aphelinus *mali.* But, in some countries controlling this pest has become a serious challenge. For instance in New Zealand, woolly apple aphid is a serious and increasing threat to the New Zealand apple industry. Growers face issues with susceptible rootstocks used for intensive plantings, a lack of Integrated Fruit Production (IFP)-compatible insecticides and unpredictable biological control outcomes influenced by seasonal temperature variations, which affect emergence and developmental rates of the parasitoid and WAA (Mols & Boers 1999; Shaw et al. 2008).

Chemical control

In laboratory studies conducted to determine the efficacy of insecticides commonly used in apple orchard in Australia, the rgano-phosphates, vamidothion and chlorpyriphos, were highly effective against WAA while fenoxycarb (insegar) did not differ significantly from a water control. The same insecticides tested against A. *mali* at three different life stages (larva, early mummy and adult) indicated that the organo-phosphates and organo-chlorines had a high kill rate at larval and adult stages. The mummy stage was less affected by these chemicals suggesting that timing of sprays is critical for maximum protection of the parasite (Fitzgibbon, 1996).

Nicholas et al. (2003) reported that Imidacloprid provided excellent control of woolly aphid on the trees that were 17-years-old at the start of the study and continued to do so for four seasons. Pirimicarb appeared to offer some suppression of woolly aphid durjng the first season but not in subsequent seasons, while chlorpyrifos and vamidothion failed to control woolly aphid in any season.

Biological control

Aphelinus mali.

The egg parasitoid, *Aphelinus mali* (Hald.) (Hymenoptera: Encyrtidae), is a specific endoparasitoid of WAA. Native to North America, *Aphelinus mali* (Haldeman) (Hymenoptera: Aphelinidae) is an arrhenotokous parasitoid of the woolly apple aphid and other species in the genus *Eriosoma*. *A. mali* is the main natural enemy of arboreal woolly apple aphid colonies in North and South America, Australia, Spain, Italy, Zimbabwe, Tadzhikistan, Israel, India, Iraq, New Zealand, and the Netherlands and has been successfully released for woolly apple aphid control around the world. Parasitism of woolly apple aphid by *A. mali* may be increased by the flora and cultural practices in the surrounding area. *A. mali* females usually deposit one egg per aphid host, although up to four have been observed, and lay about 100 eggs during their lives. Percentage parasitization is greater in long, narrow colonies, where more aphids are on the periphery, and decreases with increasing colony size. Parasitized aphids continue to grow, but will not reproduce. *A. mali* overwinters as a larva in aphid mummies (reviewed by Short 2003).

Factors that can limit the potential efficacy of *A. mali* include cold temperatures and its susceptibility to many of the insecticides and fungicides commonly used in apple production. Active at temperatures between 16 and 37°C, *A. mali* may not provide effective control of the woolly apple aphid at the cooler temperatures. The developmental rate and potential fecundity of *A. mali* is increased at higher temperatures, but is slower than that of the aphids (reviewed by Short 2003).

The parasitoid is made the New Zealand apple industry's primary control strategy for managing WAA and is an important factor regulating WAA populations in orchards under IFP (Shaw & Walker 1996) and is considered the most important parasitoid of WAA in apple-growing regions throughout the world (Brown & Schmitt 1994). Preferably, selective chemicals with the least disruptive effect on *A. mali* should be applied to apple trees (Bradley et al. 1997). However, carbaryl, which is widely used by growers for thinning 'Braeburn' apples, and diazinon, which is currently used for controlling WAA are both harmful to *A. mali* (Bradley et al. 1997). In New Zealand diazinon is now restricted to early season use to avoid the risk of exceeding the maximum residue limit of 0.01 ppm imposed for fruit destined for the European Union (EU) market. The parasitoid was able to suppress the lower populations of WAA in the diazinon plus carbaryl treatment and this resulted in significantly lower levels of WAA shoot and fruit infestation and bud damage (Shaw and

Wallis 2009). In Romania, the population of *Eriosoma lanigerum* was effectively controlled by the parasitoid wasp *Aphelinus mail* Hald (Trandafirescu, 2004).

Altogether, 73 species of predators have been recorded to prey on woolly apple aphid worldwide. Species of the families Coccinellidae, Miridae, Chrysopidae, and Forficulidae are the most common predators observed (Asante 1997).

Rootstocks resistant to wooly apple aphid

The Malling-Merton series of rootstocks, parented by the apple variety, Northern Spy were bred for their resistance to woolly apple aphid and are currently the only recommended control for edaphic populations. The Malling-Merton series of rootstocks (MM106 and MM111) were developed more than one century ago (reviewed by Short, 2003). Recently, a new series of rootstocks is being developed by the Geneva rootstock breeding program, some of which are resistant to woolly apple aphid. The resistance is based on *Malus robusta*, and apparently confers a higher level of resistance than the older Malling-Merton series (http://jenny.tfrec.wsu.edu/opm/displayspecies.php?pn=410, accessed in December 2012). From the Geneva rootstocks breeding program apple tree rootstock named G210 has been patented (Fazio et al., 2012). Therefore considering the low efficacy of chemical insecticides to control the aphid, looking for resistant cultivars that could serve as rootstock is the best option to manage the pest. But the arboreal infestation has to also be addressed using resistant scion sources. Resistant scion source variety development targeting to reduce aerial infestation was done by Ateyyat and Al-Antary (2009) who evaluated nine apple cultivars and identified one cultivar, which sustained near zero damage from the aphid.

Management of WAA

Beers et al. (2007) studied the management of wooly apple aphid. Alternatives to organophosphate pesticides have been tested for several years. Of these, petroleum oil shows some promise, as does a particle film used for sunburn protection. A neem-based insecticide provided temporary suppression, as did several neonicotinyl insecticides. A second approach to management is that of controlling the root colonies was explored for the first time. In potted tree assays, several compounds including imidacloprid, spirotetramat and oxamyl showed good root and systemic activity: in field trials, however, results were more variable. A greenhouse test of 8 clonally propagated rootstocks and 2 seedling rootstocks demonstrated that several of the new Geneva rootstocks to have virtual immunity to a Washington strain of woolly appleaphid, whereas

the older Malling-Merton rootstocks had a lesser degree of antixenosis (Beers et al. 2007).

Conclusion and recommendation

Apple is recently introduced fruit crop to Ethiopia and it is expanding and covering more hectares. Therefore in order not to hold back the spread of apple technology in Ethiopia; it is of paramount importance that different management options including use of synthetic insecticides and physical control measures be communicated to growers aggressively by devising a fast track for reaching most growers in the shortest time possible. The short term plan should therefore be mitigation of the spread of the aphid, which could be done by providing trainings on the WAA to development agents and distributing posters and leaflets to create awareness at the wider scale. The sustainable solution to control the infestation bulding in the soil is to use WA resistant rootstocks including from the Malling-Merton and the Geneva collections. To check the areal infestation the introduction and use of the egg parasitoid *Aphelinus mali* (Hald.) be considered.

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The Status of Pea Weevil, *Bruchus pisorum* (Coleoptera: Chrysomelidae) in Ethiopia

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Introduction

Among cool season food legumes, field pea (*Pisum sativum* L.) is the second most important crop grown in Ethiopia (Hailu et al. 1994). Recently the production and productivity of field pea is increasing. For instance, between the year 2000 and 2009 the area under field pea grew by 3.5%, where as yield per hectare and total production grew by 5% and 8.4%, respectively. However, compared to other field pea producer counties, the current productivity of field pea (about 11.5 q/ha) in Ethiopia is very low. There are many reasons for this, one of these and the most important is insect pests (Asfaw et al. 1994).

According to Kemal and Tibebu (1994) out of the ten insect pests that attack field pea, pea aphid, *Acyrthosiphon pisum* and pod borer, *Helicoverpa armigra* are the most important ones, which cause damage ranging from 29 – 75%. However, the recently introduced pea weevil, *B. pisorum*, which was not known as pest of field pea before, is another economically important insect pest of field pea. Despite its common name, the pea weevil is neither true weevil nor true storage pest. It is believed that the insect is native of west Asia (Miles et al 2007), but according to Davidson and Lyon (1987) the pea weevil is native of North America. Any organism occurring outside its natural distribution is considered as invasive (alien) specie. Richarson and Pyšek (2004) stated that invasive species are those that are alien to the ecosystem under question, and whose introduction causes, or is likely to cause, economic or environmental harm to human health. For taxonomic groups with less well resolved taxonomies and for which detailed species lists are often lacking, determining whether a species is native to a given area or has arrived via human transport is much more difficult. In Ethiopia, there is no insect inventory system, thus, in the absence of such inventory it is possible to argue that *B. pisorum* might not be an invasive species.

This weevil starts attacking pea at the field and continues its damage in storage. It is widely distributed in north and south Gondar, west and east Gojam, and south Wello in the Amhara National State; central Shewa in Oromiya National State and southern and central part of the Tigray National State (Kemal et al 2008). Worldwide it is widely distributed in North and South America, Europe, Australia, Asia and Africa (Walker & Boxal 1974, Hill 1983). The objective of this review is to discuss and bring together available information in Ethiopia and elsewhere on the biology, pest status, and management of *B. pisorum*.

History of pea weevil in Ethiopia

The history of pea weevil in Ethiopia is based on circumstantial evidences and the date on which the pea weevil was reported as pest of Ethiopian field pea is conflicting. Tsedeke (2006) believed that the insect might have been introduced in the mid 1970 whereas Brihane (2002) and Worku (2002) believed that the year 1988 and the year 1992, respectively, as the time of introduction. Worku (2002) indicated that "the pest was first noticed in Ibinat in 1992," but farmers in Inbinat (Ebinat) district stated that they were aware of the pest five years earlier and believed that it was introduced to their area with seeds purchased from Belesa district. Farmers in other areas such as Zequala (Gojam) also believed the pest was introduced from Belesa (Adane et al 2002). Adane et al (2002) also indicated that the pest was reported in the late 1940s around Asmara, Eritrea. Belesa was the strong hold of the National Amhara Democratic Movement, the then Ethiopian People Democratic Movement (EPDM). Therefore, it is possible to speculate that the insect pest might have been introduced to Belesa with military rations and armaments. It has also been indicated that the pest might have been introduced with food aid (Worku 2002) or through local seed movements (Kemal et al 2008).

Biology of the Pea weevil

Although Birhane (2002) studied the biology of pea weevil under Ethiopian condition, the study lacks clarity. First, the pea variety used in the study is not known. Second, the source/ culture and age of pea weevil used in the study are not known, and hence, there is a probability of underestimating the number of eggs laid by a female. Third, the study was not supported by quantitative data on environmental variables that happened during the study period. Therefore, detailed investigation on biology and ecology of the insect pest is required to understand the aestivating, hibernating and infestation times. Therefore, the following account on biology of pea weevil was compiled from sources outside Ethiopia. The pea weevil is univoltine specie completing only one generation per year. The females lay their eggs on developing pods; eggs are first laid on

young pods by the time when the flower begins to wither. Eggs hatch in about 6 -14 days. They are shiny bright yellow/orange, 1.5 mm long and attached singly to developing pea pod. This may last 6 -10 days depending on environmental conditions (Garry 1995).

The larva burrows directly through the pod where it feeds and develops in the developing seed. There are four instars. Each developing pea seed in a pod supports one developing weevil larva. After feeding for 40 to 50 days, the fully grown larva prepares 2 to 3 mm exit holes by chewing partly through the seed coat. The larva is C-shaped, up to 6mm long, legless, brown-headed and cream-colored. The larva then pupates and after about two weeks changes into adult beetle. By this time the seed has usually been harvested and some beetles emerge from the stored seed to find suitable hibernation site, others may remain within the seed. The pea weevil emerges about the time the peas are blooming, feeding on flowers (pollen and petal), leaves or pods (Garry 1995).

Adults are brownish flecked beetles with black, white and grey patches. They are about 5mm long. The tip of the abdomen (body) extends beyond the wing covers. The portion of the abdomen that is visible is white and marked with two black spots. It has a small head, 11 segmented antennae arising in front of the eyes and it bears a very short rostrum (fig. 1) (Garry, 1995). The sex of *B. pisorum* is easily determined. Males have a small, but visible with a microscope, acute 'spine' on the distal end of the tibia of the middle leg. This spine is absent in females (Stephen personal communication).

The adults overwinter, with the peas primarily in storage, around sheds, silos, under the bark of trees and in cracks and crevices in posts, also in the field. They resume activity when temperature reaches about 20 ^{0}C and fly to the edge of the nearest pea crop (Greg, 1998).

Temperature and photoperiod affect the developmental period of *B. pisorum* either by lengthening or shortening. The development thresholds and effective temperatures were 9.4 ^{0}C and 47.2 degree-days for eggs, 7.3^{0}C and 289.1 degree-days for larvae and 8.4^{0}C and 55.4 degree-days for pupae. The optimum temperature range for growth was 27-33^{0}C in Southern Korea (Park *et al.* 1991).

It is possible to get viable eggs in the laboratory by keeping the beetles in conditions where the light intensity at the top of plants at 19 lx, the photoperiod 16h before the appearance of the first pods and 14h thereafter, the temperature

range of 16 to 26^{0}C during the day and from 14 to 22^{0}C during the night and the relative humidity of 40 – 70% (Norambuena and Mera 1986). Adults feed on pollen, as pollen is required by females to develop eggs. Females need to exhaust their fat reserves, or to reorganize them after feeding, for the successful development of eggs. A single female pea weevil has the capacity to lay over 400 eggs during her life cycle that can result in significant damage with low number of adult pea weevil (Greg, 1998).

Economic Importance of *B. pisorum*

Estimates of losses caused by pea weevil on field pea are available from different regions of Ethiopia (table 1). The damage and weight loss caused by *B. pisorum* could reach to 85% and 59%, respectively. Field pea seeds with black dots were considered as infested by pea weevil, although such symptoms can be caused by some other factors. Similarly, the type of grain considered as damaged grain was not well defined. Therefore, part of the infested and the damage grains might fit for human consumption, which suggest that the infestation and the damage estimate are inflated.

Table 1. Estimates of damage and weight loss caused by *Bruchus pisorum* on field pea

Sample collection area	Infestation (%)	Damage (%)	Weight loss (%)	Reference
Ebenat	48-83	24-49	8-17	Worku 2002
Adet and Bahir Dar Zuria	-	25-55	-	Adane et al 2002
Achefer		50-60		Kemal et al 2008
Achefer	-	14-46	-	Adane et al 2002
Sekota	-	53-80	27-59	Adane et al 2002
Sekota	-	80-85	-	Kemal et al 2008
Hagerselam (Gondar)	-	79	-	Kemal et al 2008
Kimbaba (Bahir Dar)	-	66	-	Kemal et al 2008
Temben	-	53	-	Kemal et al 2008
Mekelle, Maichew, Mehoni		7-12		Kemal et al 2008
Kurkura (Debre Zeit)		-	13.5	Kemal et al 2008

Studies conducted in Australia showed that infestation of organic pea seeds by *B. pisorum* led to a 90% decrease in germination (Fischl et al. 1997). Similarly, infestation of peas by *B. pisorum* in the former USSR reduces the weight of the peas by 30% and their germination capacity by 70-90% (Negrobov and Petrishcheva 1979).

Damage by pea weevil consists of a complete or partial destruction of infested seeds by forming numerous round holes or destruction of all but the outer shell.

Pea weevil larvae can reduce yield directly by consuming the seed or by increasing the number of peas split during threshing. Insect contamination may cause reductions in quality. Heavily infested pea crops may have up to 15 to 20 percent of the pea seeds attacked by pea weevil larvae. Infested seeds can lose up to 25 percent of their weight from larval feeding, and are prone to shattering when harvested (Greg, 1998).

Host range of *Bruchus pisorum*

Bruchids show wide variations in their host range. The host range of the individual species is variable and each species fails to breed on one or more common pulses. The incompatibility of such pulses is determined by the presence in their seeds of certain non-protein amino acids, lectins or other secondary substances which afford protection against bruchid attack. Host specificity is decided by the indispensable feeding habit of the adults on the pollen and nectar of the host (Pajni 1987).

Pea weevil is a monophagus insect feeding only on the genus Pisum including pea, *P. stivum subsp asiaticum*, wilde pea, *P. stivum subsp elatius*, *P. stivum subsp sativum*, *P. stivum subsp transcaucasicum*, and Australian winter pea, *P. stivum subsp arvense* and *P. fulvum*. Other than field pea Adane et al (2002) listed about eight legume species and maize as host of pea weevil. Some of the hosts mentioned such as *Cicer arietinum, Lens culinaries, Latirus stivus* and *Zea mays* are grown in most areas of Ethiopia where pea weevil is a problem, but so far the insect was not reported as pest of any of these crops. The three aforementioned legumes are planted later than field pea and may set pod before the pea weevil complete its lifecycle on field pea which increases the chance of escaping infestation. According to Pajni (1981) the reason adults of pea weevil hibernates in and around sheds, in soils, under barks etc is to feed on other plant species. Also few literatures indicated that it feeds on pollen of certain tree species (CABI 2007).

According to Rawy et al. (1971) it is a major pest of broad beans (*Vicia faba*) in Irag. The eggs of the weevil are laid in the soil near the bean plants and the larvae move to the roots and feed principally on the nodules. Pupation occurs in the soil and when conditions become suitable; adults emerge and come to the surface. The adults feed on the leave and seek over wintering sites (Sigvald 1978). The attack of the adult on the leaves can reduce the density of seedlings and feeding by the larvae on the nodules and the roots reduce vegetative growth.

Management of *Bruchus pisorum*

Although *B. pisorum* is considered as invasive specie, because of its current geographical distribution and the weak internal quarantine system of Ethiopia invasive pest management strategies such as eradication and containment are not options for managing this insect pest. Therefore, emphasis should be given for control and mitigation

Sampling and economic threshold of pea weevil

Monitoring and sampling peas at and immediately after flowering is the key to effective control of pea weevil. The ideal time to spray crops is prior to pod formation before oviposition commences. Control can only be achieved by preventing egg lying. That is, the best time when the beetles are susceptible to insecticides. If the number of beetles exceeded the economic threshold, they should be controlled at early flowering, when the beetles first fly into the crop and before they lay eggs (Greg 1998). In Ethiopia, the economic threshold level for spraying pea weevil on field pea has not been determined.

The pea weevil can be trapped using a sweep net or a butter fly net. The sweep net provides the most effective means of sampling for pea weevil. As the beetles do not fly far into the crop, sampling needs only to be conducted on the edge, starting adjacent to any nearby hibernation sites such as tree lines, sheds etc. *Bruchus pisorum* is highly active during the day, sampling on warm, humid days with no wind and avoiding areas of unusually high or low vine density has been recommended.

Available evidences show that on the average 3 beetles per 25 sweeps, taken as an average over 10 sites, is a reliable economic threshold. Ten beetles per 25 sweeps is considered a severe infestation (Garry 1995). If few or no beetles are present, it is necessary to repeat check during the flowering and early-podding stages because beetles may still fly into the crop (Greg 1998).

Infestation time

The pea weevil began infestation of field pea in Ethiopia in mid August and continued until the end of September (Adane et al 2002). Although this generalization might be true in most cases, field pea flowering time and the susceptible stage to pea weevil can be location specific and field scouting should be planned based on this specificity. The pea weevil is restricted to the boarder of field pea and scouters should focus in this area.

Intercropping

Intercropping pea with other legumes (*Lathyrus sativus*, chickpeas and lentil) has resulted in a 10% reduction in grain damage, even though it did not affect the adult population or oviposition. This was because petroleum ether extracts of the weed, lentil and lupin; dichloromethane extracts of chickpea and lentil, and methanol extracts of *L. sativus* produced a change in brucid behavior (Medina and Victor 1990; Araya et al. 1992).

Host plant resistance

The introduction of weevil resistant pea cultivars offers environmentally safe control strategy. The differences in the preference of the weevils for some pea varieties depend on the differences in distribution of plant tissues and on the biochemical composition of leaf saps. The feeding rate of weevils varies according to the year, the age of plants, the sowing date and the variety (Havlickova 1978).

In Ethiopia, the field pea genotypes screened for pea weevil resistance at Ebinat did show variation in the number of eggs/ pod and adult pea weevil number per plot (Melaku et al 2002). Similarly, on field pea genotypes tested at Denbi the number of damaged seed varied between 0 and 40 and number of larvae per 100 seeds ranged from 0 to 43 (Kemal et al 2008). The maximum damaged seed and larvae population was recorded on Helina. However, in both cases important factors such as pod length were not taken in to account and had the number of eggs for instance been adjusted for pod length, genotypes might not differ in egg number.

There are characters which are more applicable to develop resistance varieties. For example, non-preference for oviposition is the major resistance mechanism. Flat and swollen *P. sativum* pods and pods longer than 10-20 mm in length provide optimum or near optimum oviposition substrates for *B. pisorum*. Peducle length is short in resistant varieties than in susceptible once (Pesho et al. 1977).

In breeding for resistance, the best character was found to be selecting for earliness, profuse flowering and fruiting, and rapid lignifications of the pod valve tissues (Verbitskii and Pokazeeva 1980).

Bean alpha-amylase inhibitor1, which is alpha A1-1 in transgenic peas, *P. sativum* provides a complete protection from pea weevil. Alpha A1-1 inhibits pea weevil's alpha-amylase by 80% which results in blocking the development

of larva at early stage (Schroeder et al. 1995). Alpha- A1 has also inhibits human alpha-amylase, however, cooked peas should not have impact on human energy metabolism.

Addition of phosphorus (P) and sulfur(S) as fertilizer into the soil changes chemical composition of *P. sativum* especially, increases phylate and protein concentrations, which reduces the risk of infestation by *B.pisorum* in pea seeds (Marzo et al. 1997).

Content of phenolic compounds in testa and pods was higher in resistant than in susceptible varieties and this could be used as a biochemical indicator of resistance (Malakhanov 1985). Varieties that contain high level of tannins and phenol experience less damage than those containing less (Ilieva and Dochkova 1998).

Scientist have discovered chemical that causes plant tumor that can be used in developing a resistant varieties. In order to reproduce, the pea weevil needs to lay its eggs on a pea pod. But the pea plant has apparently developed an innovative and effective response to this attack. When the egg is laid, the pea plant detects in the pea weevil a type of chemical- bruchins. This chemical triggers the pea pod to begin a process of cellular division that actually forms a small tumor, lifting the pea weevil egg up and away from the pea pod. In this position it helps to prevent the emerging weevil larvae from burrowing into the pea pod. It may also fall off, dry out or be eaten by predators and reduces the chance that the pea weevil will actually succeed in infesting a pea (Keith 2000).

Biological control

Currently there is no reliable biological control identified or developed for this pest. However, *Uscana senex* Grese (Hymenoptera:Trichogrammatidae) parasitizes *B.pisorum* eggs. Approximately up to 10% reduction in seed damage was obtained. The best time to release is twice a week at the beginning of flowering until pea pods are completely filled. The rate of parasitism affected by the distance of release i.e. as the distance from a release point increase the level of egg parasitism decreases (Hormazabal and Gerding 1998). Similarly, up to 80% parasitism of *B.pisorum* larvae was reported by releasing 2female/m^2 or 1male/5m^2 of *Triaspis thoracicus* during budding stage of plants susceptible to Bruchids (Khrolinskii and Malakhonov 1979). Pupae of the tachinid *Hyalomyodes triangulifera* (*Strongygaster triangulifera*) were found in dead adults of the bruchid (Gerding and Figueroa 1989).

Cultural Control

Suppressing or controlling of *B.pisorum* using cultural control measures is possible. This is possible by manipulating the environment i.e. creating unsuitable environment for *B. pisorum*. For example, sanitation of the field, burning of the field from which peas/beans harvested, deep ploughing, crop rotation, over grazing of pea fields etc. Stores should be thoroughly cleaned before the intake of new stock. Residues of old grain, which are often infested with insects must be removed from the store, this should include the cleaning of any cracks and cervices. During construction of stores, harboring sites should be avoided.

Chemical control

Melaku et al (2002) tested different insecticide application timings using the insecticide trichlorfon (Diptrex) at Ebinat. However the tested insecticide was not effective, and so far there is no registered insecticide for use on Ethiopian field pea to control pea weevil (MoARD 2009). Therefore, selecting insecticide under Ethiopian condition is one area of future research.

The beetles after leaving their hibernation sites usually settle at the crop edges (the outer 10 to 15 m) and then disperse further into the crops by a series of short flights. Most pea weevils remain near the edges of pea crops throughout the invasion periods. Hence, pea weevil can be cost effectively controlled with a well timed border spray. The female beetles are sexually immature when they leave hibernation and have to feed on pea pollen and need further time for ovarian development. On the average, the time taken from the first arrival of pea weevil in flowering pea crop to the first egg laying is about 2 to 2.5 weeks. This delayed egg laying is important to determine the optimal date to spray pea crop to control. This is because eggs on pods and larvae in pods are almost immune to available insecticides. The larva is immune because it immediately bore into the pods and is never exposed to the insecticide. For this reason, the adult pea weevil must be controlled before egg laying commences.

From insecticides registered for the control of pea weevil elsewhere, endosulfan was the most effective, followed by bifenthrin. Lambda-cyhalothrin, Beta-cyfluthrin and cyfluthrin were less effective. Mixing insecticides was also more effective. For example, endosulfan mixed with thiometon was as efficacious as endosulfan alone, Tau-fluvalinate + thiometon gave reasonable control and cypermethrin and its isomers was also suitable for use (Taupin et al. 1999). The combination of dimethoate and imidan treated early had significantly greater control of pea weevil than baythroid and single dimethoate application.

Insecticides, such as, Basudin (diazinon) 40wp, volaton (phoxim) 50ec or dursban (Chlorpyrifos) 40ec were all effective at 1kg/ha against the *B. pisorum*, which reduced seed infestation from 5-7% in untreated plots to 0.05-0.64%. Single application of clorpyrifos either at the beginning of or during flowering gives effective control of pea weevil. The pyrethroid most effective against this pest was decis (deltamethrin) 2.5ec applied at 0.15-0.3 lit/ha seed infestation being reduced from 3-5% to 0.06 % (Khimera 1987).

Cypermethrin acts as a knockdown insecticide against *B. pisorum*. In the field, cypermethrin at 40g ai/ha or endosulfan at 350g ai/ha reduced damage by the pest from 11% in unsprayed peas to 4%. Cypermethrin is best in pea crops because of its relative persistence and its activity against both *B. pisorum* and other pea pests (*Helicoverpa punctigera*) (Horne and Bailey 1991).

A good level of control of *B. pisorum* using insecticide can be obtained with a single application at the young flat pod stage of the second flowering levels. If two applications are made these should be at the beginning of flowering and 8 - 12 days later.

Fumigation

The pea weevil population is mostly at third instar at the time of early harvest and at this stage, only 26% of the maximum possible damage (seed weight loss) has occurred. Hence about 74% of seed weight loss can be prevented by an early harvest and fumigation of the crop immediately following harvest. The sooner it is done the better to minimize weight loss (Zakladnoi 1987).

Silo fumigation of bulk peas with aluminium phosphide tablets is the most effective method. Peas seed in sacks/bags can also be fumigated with aluminium phosphide as lay down gas proof plastic sheeting and stack the bags on it. The sheeting should be large enough to be able wrap the stack and contain the fumigant. Add one tablet of alluminium phosphide to each bags then cover the stack for 5-12 days. Then remove the cover and air the bags for another 5 days (Garry 1995).

Solar heating

Solar heating immediately after threshing or later than six months was not effective in reducing larvae / pupae reaching adult stage (Melaku et al 2002).

Inspection techniques

To avoid unintentional introduction of pea weevil, enquires should be made about the presence of pea weevil. The usual way of inspecting introduced germplasms for quarantine pests is visual inspection or use of low powered stereoscopic microscope (Awgachew 2002). If the volume of pea is large inspection is done by collecting samples (1-2kgs) in plastic bags, shaking vigorously and securely tying the bag. Check for the emergence of beetles after a few hours. Sampling and checking in this way should be repeated monthly up to the time sowing.

The best and easier technique of inspection is to soak peas in water to make them swell and soften and facilitate cutting and checking peas internally for immature stages of bruchid. This increase the efficiency of detection compared to visual methods of external examination. If beetles are detected even in only some bags all of the stored seed should be fumigated (Somerfield 1989). With in this method it is estimated that it is possible to detect infestation of 0.5-1% with in a few minutes. Other more expensive methods are described in CABI (2007).

Recommendations and future strategies

- Use field pea varieties that are resistant to pea weevil
- Practice field sanitation (avoidance of growing peas near crops and weeds that could supply insects).
- Damage can be kept to a minimum by harvesting the crop as soon as possible.
- Deep plough stubbles to prevent larval emergence
- Apply chemical control at field edges to a width of 40 meter. Most pea weevil insecticides provide a good knockdown of adult beetles for 4 to 7 days after spraying. One well timed border spray will provide good control of pea weevil, for example, when 50% of plants have flowered and if still there is an infestation it is better do spray again 8 -10 days later. Correct spraying time is the key to achieving good control of pea weevil; this is best if it is done before they lay eggs on pea pod.
- Immediate ploughing, burning or heavy grazing reduces the likelihood of volunteer peas surviving as hosts for weevil in subsequent years. This is because most of the infested peas that remain will be eaten and the remainder will be exposed to direct sunlight which causes high mortality of pea weevil larvae.

- Store only clean, dry seeds with moisture content of 12% or less to reduce damage.
- Provide a clean, dry storage area.
- Inspect periodically
- Never plant infested peas
- Do not plant peas near alfalfa or clover since pea weevils are often found among these plants.
- Plant peas as early as possible
- Fumigate the yield immediately after harvest
- Even though it is a serious pest of pea in Ethiopia, there is no information on its biology, ecology and management. Therefore, it is strongly recommended to under go research on the biology, ecology and management which contribute towards the development of sustainable management of *B .pisorum*.

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Research progress on invasive woolly whitefly (Homoptera: Aleyrodidae): a threat to citrus in Ethiopia

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Introduction

Several insect pests namely woolly whitefly (WWF), false codling moth, fruit flies, citrus leaf miner, citrus thrips, red scales, and woolly apple aphid are known to inflict damage on fruit crops in Ethiopia (Azerefegne et al. 2009). Although a systematic study and analysis need to be done, yield loss on fruit crops due to insect pests is currently estimated to be more than 30 percent. With the exception of red scales, the other pests are either recent introductions or achieved pest status because of reliance on insecticides as a stand-alone solution in their management especially in commercial farms. This has led to further complications in terms of pest status of such previously known resident species. The development and wide spread scenario in terms of resistance to pesticides is for instance an example for that. In recent past, studies on fruit pest management had concentrated on identification of effective insecticides to develop control methods. These include mainly insecticidal screening trials against WWF, false codling moth, med fruit fly, citrus thrips, and citrus leaf miner. However, reliance on insecticides for pest management especially introduced and invasive species such as wooly whitefly is both unsustainable and ineffective (De Bach and Rose 1976). Biological control based on a sound knowledge of the ecology of pests and their natural enemies is the best alternative (Miklasiewicz and Walker 1990). The WWF is a new insect pest to Ethiopia. The pest has not been included in the list of insect pests of horticultural crops compiled about two decades ago (Abate 1988) although the possibility of its introduction to Ethiopia was anticipated (Abate 1992).

This pest was reported for the first time in East and Central Africa in the early to mid 90s with heavy damage to citrus in several countries in the region (Lohr 1997). Its occurrence in Ethiopia was detected from leaf samples collected from orange trees planted in homesteads around Wonji and Nazareth towns in December 2000, the identity of which was confirmed by Dr. Bernhard Lohr of the International Center of Insect Physiology and Ecology (ICIPE). Its occurrence in Ethiopia however was made public during the 11th annual conference of the Crop Protection society of Ethiopia (Getu et al. 2003).

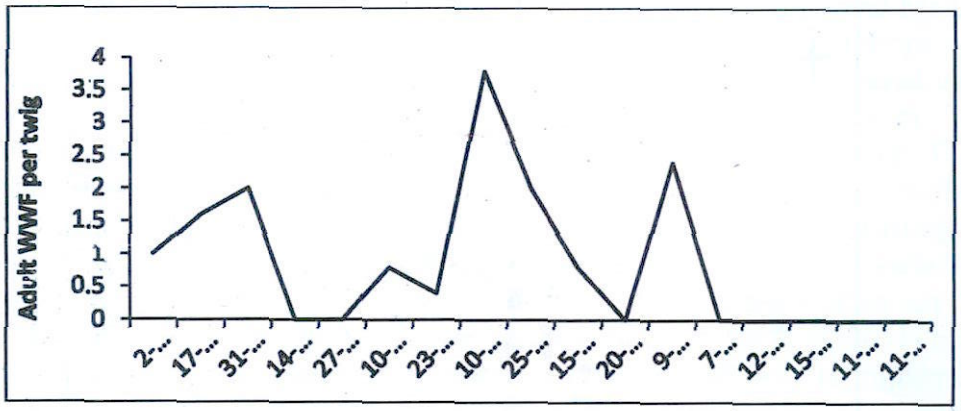

Fig. 2. Adult woolly whitefly number per twig on navel orange at Melkawoba in 2009/10 (After Ayalew, 2010)

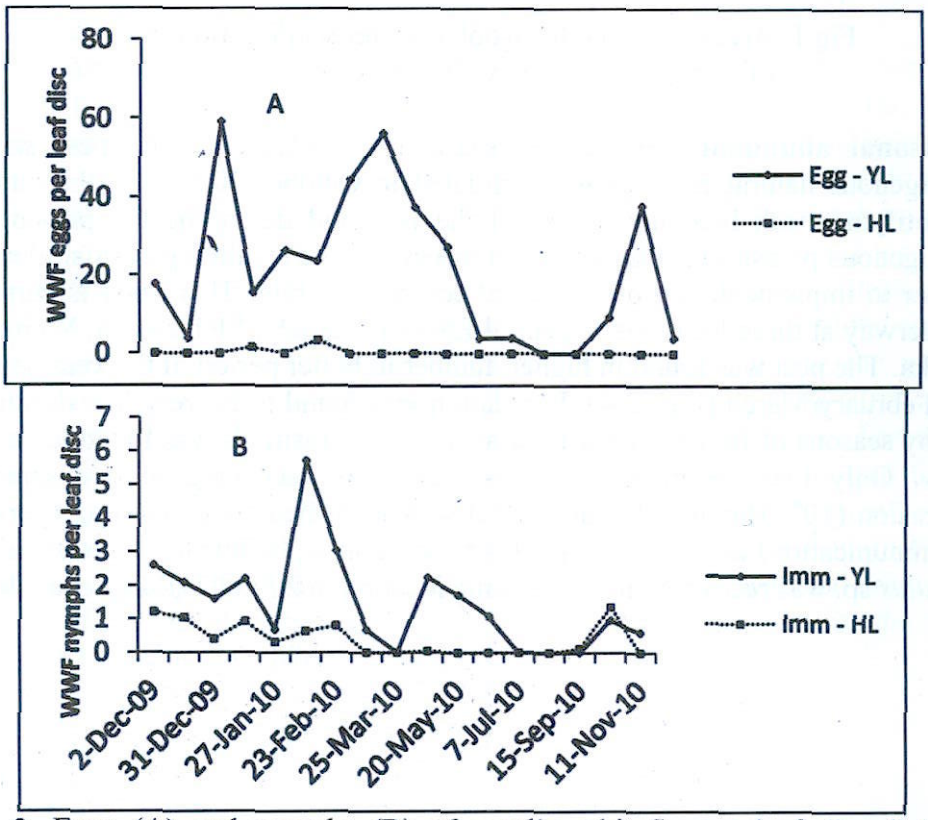

Fig. 3. Eggs (A) and nymphs (B) of woolly whitefly per leaf disc (1.5cm diameter) on young (YL) and Hardened leaves (HL) of Navel orange trees at Melkawoba in 2009/10 (After Ayalew, 2010).

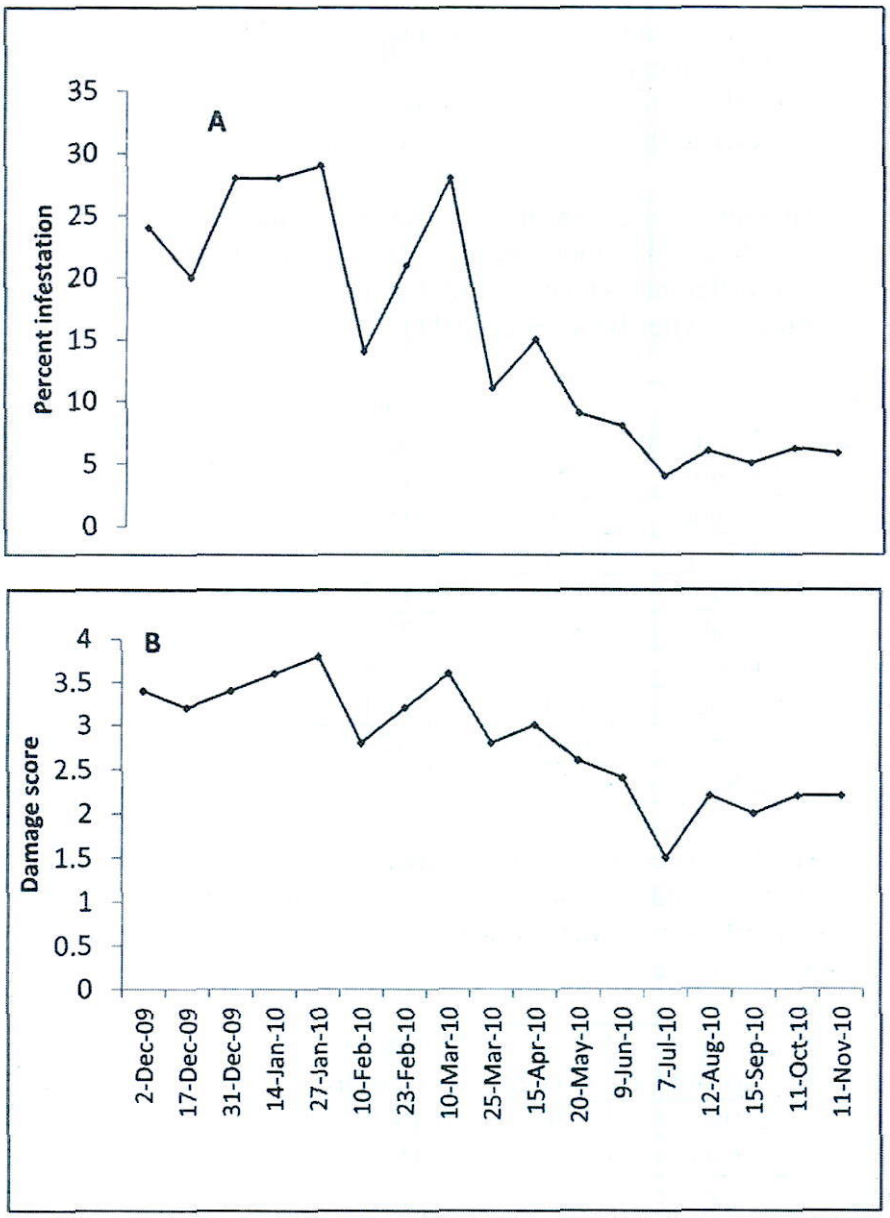

Fig 4. Infestation level (A) and damage score (B) of woolly whitefly on navel orange at Melkawoba in 2009/10 (After Ayalew, 2010)

Management studies

Insecticidal control Synthetic and botanical insecticides were screened against the pest at Melkawoba and Nazareth in 2006/07 (Tables 1 and 2). This has

in WWF population was reported from Moroco and France (cited by Miklasiewicz and Walker 1990) in a year period.

To minimize the problem of WWF in citrus production in Ethiopia, there is an urgent need to import effective and proven parasitoids of the pest such as *Cales noacki* and release them both in homesteads and commercial farms where the pest is established. As pesticide use in homestead is either absent or very minimal, implementation of the biocontrol program is expected to be easier. In commercial farms where pesticides are used extensively for the control of several pest species, there is a strong need to shift from use of broad spectrum pesticides such as Selecron and Cyhalothrin to selective and IPM compatible ones. This entails pesticides screening study on effectiveness and safety to the pest natural enemies. To prevent or slow woolly whitefly invasion, movement of nursery stock from one region to another must be based on strict quarantine. Until biological control becomes available, hosing the lower leaf surface of trees infested with WWF with high pressure water in homesteads helps to mitigate the pest problem.

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Invasive Alien Weed Species in Ethiopia: Status and Management

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Introduction

Invasive alien plants (IAPs) are plant species entering new regions of both arable and non-arable lands and detected as noxious potential to terrestrial and aquatic habitats. A plant is noxious when the interaction threatens man's activities or the native flora and fauna. Invasive plant may also have a substantial effect on the environment, agricultural production and human welfare.

Currently, over 35 IAPs are of a great concern in Ethiopia, of these, *Prosopis juliflora*, *Parthenium hysterophorus* and water hyacinth (*Eichhornia crassipes*) in particular have become a high-profile policy topic requiring immediate action to improve and speed the effectiveness of efforts to combat these obnoxious plant invaders. These species severely threaten biodiversity, habitat composition, ecosystem functions and human welfare and are displacing the native species causing reduction of biodiversity of native flora and fauna (Rezene, 2008; Taye et al., 2009c). This paper presents an update on the spread and distribution status of major invasive alien weed species in Ethiopia and provides a summary of the initiatives, achievements and research opportunities in order to explore the options available for their management.

Table 1. Top 20 Invasive Alien Plants in Ethiopia

Species	Ecosystems highly affected*	Distribution status
Parthenium hysterophorus	*1,2,3,4,5,6,7,8*	*High*
Prosopis juliflora	*1,2,3,4,5,6,7,8*	*Moderate*
Opuntia ficus-indica	*3,4,5,6,*	*Moderate*
O. stricta	*3,4,5,6,*	*Moderate*
Mimosa diplotricha	*1,2,3,4,5,6,8*	*Moderate*
M. pigra	*3,4,7*	*Low*
Cryptostegia grandiflora	*2,3,4,7,8*	*Low*
Lantana camara	*1,2,3,4,5,6,8*	*High*
Acacia drepanolobium	*1,3,4,*	*Moderate*
A. saligna	*2,3,4,5,*	*Low*
Parkinsonia aculeate	*2,4,5,6*	*Low*
Nicotiana glauca	*1,2,3,4,5,6,*	*Moderate*
A. ochroleuca	*1,2,3,4,5,6,*	*High*
Xanthium strumarium	*1,2,3,4,5,6,*	*High*
Xanthium spinosum	*1,2,3,4,5,6,*	*Moderate*
Psidium guajava	*8*	*Low*
Senna didymobtrya,	*1.2.3.4.5.6.8*	*High*
Calotropis procera	*1,2,3,4,5,6,7,8*	*Moderate*
Ricinus communis	*2,4,5,6,*	*Moderate*
S. occidentalis	*2,4,5,*	*Moderate*

*1 = Cultivated land, 2 = Roadside 3 =Grazing areas
4 = Non-cultivated land 5 = Rural villages 6 = urban areas
7 = Riverside 8 = Forest areas

Source: (Rezene, 2011d)

Alien Weed Invaders in Terrestrial Ecosystems

Prosopis juliflora

Initially *Prosopis juliflora* was introduced to Ethiopia some 40 years ago as a forestry tree in the Awash Basin. The major objectives of its introduction were to provide supplementary animal feed and erosion control. But, the species had invaded a substantial area of agricultural land and dominated the under growth of most riparian forest of ANRS. But now it is threatening the protected areas of Awash National Park as well as pastoral and irrigated agricultural land of the middle and lower Awash basin; eastern part of Harerge, the Wabi Shebele Basin in the Somali Region and several localities of the Raya Azebo plains of southern Tigrai and neighboring localities of North Welo. Invasions of Prosopis are also reported in the Arba Minch and neighboring localities close to the Netchsar National Park in the Southern Region of the country (Rezene, 2008

and 2011a; Getu, 2008; Mohammed, 2010 and Serawit, 2010). Distribution of *Prosopis juliflora* in Ethiopia is presented in Figure 1.

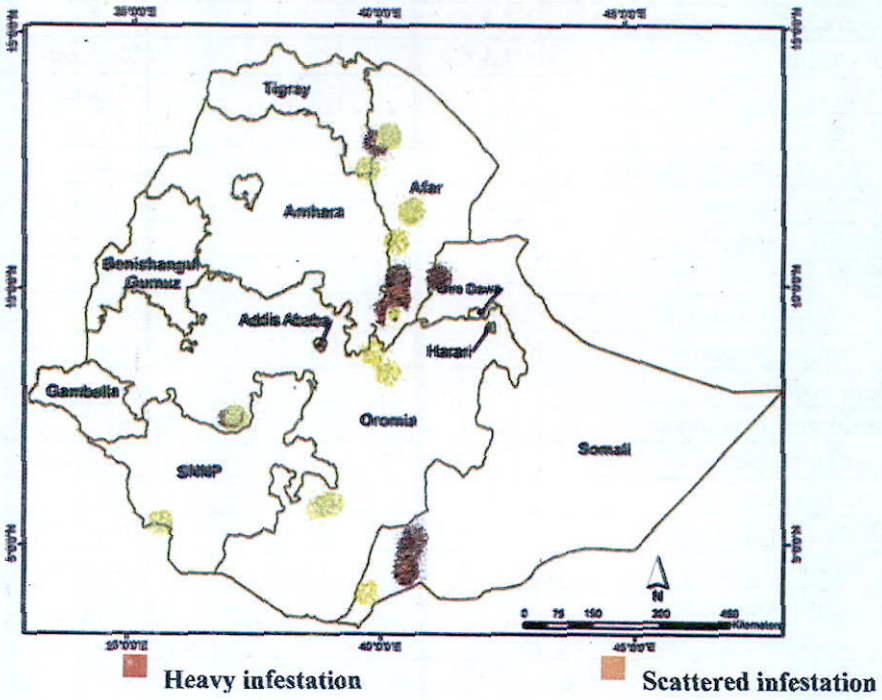

Fig 1. Distribution map of prosopis juliflora

Prosopis invasion is estimated well above 700, 000 hectares of prime grazing and irrigable land in Afar region alone and the spread of the plant is advancing at the rate of about 50,000 hectares annually. Prosopis was introduced without comprehensive impact assessment of its potential effects on the environment. This species is known for its numerous harmful effects on the livelihood of the local pastoralists in Afar and Somali Regions (Hailu et al., 2004; Senayit et al., 2004; Getu, 2008; Taye et al., 2009; Rezene 2011a). Currently it is fast expanding and has made natural regeneration and under story growth impossible under the forest floor of the riparian forest. It is worth noting that, *Prosopis* has competed out the native tree species, particularly the Acacias in many places of the affected areas of the ANRS and neighboring localities (Senayit et al., 2004; Hibret, 2008; Tamene, 2009 and Tamene et al., 2011).
Although *Prosopis* has also been considered as a soil stabilizer, it likely has and/or will dramatically affect the hydrological cycle which is a critical

resource in much of the arid Afar region. *Prosopis* also reduces the productivity of pastoral country by taking over grasslands and using valuable water resources.

Communities Perception on Prosopis

A socioeconomic study results in Amibara District revealed that the invasion of Prosopis has caused multiple negative effects on the livelihoods of the pastoral communities and the natural environment (Senayit et al., 2007).

Due to the invasion of Prosopis, communities are unable to access rangelands, waterways and causing health problems both on humans and livestock. Moreover, the encroachment decreased rangeland and grass availability, denied access of livestock to available grass, the prosopis thicket has become home for harmful wild animals like hyena, jackal and snakes. With increase in the plants encroachment grass and herbaceous biomass production has been negatively correlated. Palatable indigenous pasture species such as *Chrysopogon plumulosus, Cenchrus ciliaris* and *Setaria acromelaena* have been reduced due to the Prosopis invasion. Coupled with the recurrent drought common in the area, this has reduced livestock production and productivity and affected the pastoralists' livelihoods that are predominantly dependent on livestock and livestock products. Indigenous trees population such as *Acacia tortilis, A. senegal* and *A. nilotica* are declining in the rangeland due to *Prosopis juliflora* invasion. Pods and branches of these trees used to be the main dry season feed sources for livestock affecting their herds (Senayit et al., 2007). Moreover people and livestock suffer from injuries from the sharp and poisonous thorns of Prosopis. Livestock poisoned and wounded cannot travel long distance to look for grazing which reduces their productivity. In the worst cases the animals die due to secondary infection from the wounds which resulting in significant losses to livelihoods (Senayit et al., 2007).

Threats of *P. juliflora* to biodiversity in Awash National Park,

Analysis on woody plant diversity conducted at Awash National Park showed that *Prosopis juliflora* contributed to 0.67% of total tree density with 3.52 cm DBH and was found spread in different parts of the park particularly following the routes of cattle movement and where cattle stay for long time. It was observed along northeastern border of the park along the road from "Geda camp" to "Filweha" and around the southern foot of Mount Fentale which are the main entrance of cattle from Afar and Ittu/Kereyu pastoralists respectively (Tamene, 2009 and Tamene et al., 2011).

Impacts of *P. juliflora* Invasion on Plant Biodiversity and Soil Properties in Amibara

A total of 88 plant species in 30 families were recorded of which, 76% were herbs, 14% were grasses and 10 % were woody species. The vegetation data of all sites showed that *P. juliflora* had less species diversity (Shannon diversity index, H` =3.1) as well as species richness under its canopy as compared to *A. nilotica* (H`=3.6) and *A. tortilis* (H`=3.2). The species diversity of highly Prosopis invaded site (Adobtolle) was less (Shannon index, H`=2.99) than to that of less Prosopis invaded site (Assoba) which had H`=3.63). Among the woody species, *P. juliflora* dominated outside the fenced area. Its frequency of occurrence increased from 3% to 23 % from fenced to unfenced area respectively. The frequency of occurrence of herbs decreased from 70% to 60% from fenced to unfenced area respectively indicating that the decrease of herb with increase of occurrence of Prosopis both in inside and outside the fenced area.

The soil physical properties such as bulk density ranges between 0.5-2g/cm^3, sand ranged between 10 and 80 %, higher silt content (49.28%±2.49) under canopy of Prosopis than the two *Acacia* species. Clay content was higher under *P. juliflora* (33.25±1.24%) than open land (27.3±1.45%). The soil chemical properties such as pH, Ca, Mg, Na, K, P, SOC, TN, CEC showed that pH values was > 8 and the concentration of Ca, Na and K was found less under the canopy of Prosopis than open land and the two Acacia species as well as in highly Prosopis invaded site showing that Prosopis has potential to ameliorate sodic soils. The soil had EC values between 0.5 to 1.75 ds/m and higher under the canopy of *P. juliflora* (0.75ds/m) than open lands. The exchangeable base cation concentration values ranged from 58-86 for Ca, 25-45 for Mg, 0.8-1.8 for K and 5-14 Meq/100 g soil for Na showed that Ca availability increased with a decrease in the invasiveness of Prosopis, while Mg availability increases with an increase in the invasiveness of Prosopis species. Available K varied significantly from a value of 1.00 meq/100 under the canopy of *P. juliflora* to 4.00 meq/100 g soils at surface soil horizons under the canopy of A. *nilotica*. On the other hand, the concentration of Mg,, available P, %OM, CEC, EC were relatively higher in both under the canopy as well as in highly Prosopis invaded site than open land and under canopies of the two *Acacia* species. In general, this study showed that Prosopis had less diversity of undergrowth herbs and grass species than the native *Acacia* species and has a potential to reclaim salt affected soil of the area (Ameha, 2006).

Allelopathic effects of *P. juliflora*

A study on the allelopathic effects of aqueous extracts of leaf, bark and root of *P. juliflora* on germination percentage, germination rate and seedling growth of *Acacia nilotica*, and *Acacia tortilis* (Fabaceae); *Cenchrus cillaris* and *Enteropogon rupestris* (Poaceae) indicated that the effect is species specific and leaf seems to contain greater amount of inhibitors than does bark and root. Bark seems to contain the least. Heavy accumulations of leaf litter under *P. juliflora* result in accumulation of toxic substances in soil layers, inhibiting growth of other species. This may be one of the main reasons for its invasiveness and low plant diversity seen under its canopy (Samuel, 2010). Comparatively, germination of *A. nilotica* and *A. tortilis* was not affected by all treatment types. Leaf and root extracts at higher concentrations inhibited germination of *C. cillaris* and *E. rupestris*. Bark extract facilitated germination of *C. cillaris* at lower concentrations. In general, all treatment types speeded up the germination rate for *A. nilotica* and *A. tortilis* at the beginning, while these slow down the germination rate of *C. cillaris* and *E. rupesteris*. Shoot and root growth of the studied species was inhibited by leaf extracts while bark extracts were stimulatory to shoot and root growth at lower concentrations except for *C. cillaris* whose root growth was not affected by bark extracts at similar. Root extracts were stimulatory at lower concentrations while it was inhibitory at higher concentrations to shoot and root growth of the studied species except for *C. cillaris*. *C. cillaris* shoot growth was not affected by root extracts at lower concentrations. Seed germination of all study species except *A. nilotica* was inhibited by the amended and under canopy soil. The effect was high on the grasses than on the tree species studied and root growth was more inhibited than shoot growth. Suppression of seed germination, facilitation or retardation of the germination speed and seedling growth of the studied species suggests that these responses are attributed to an allelopathic effect of *P. juliflora* on the test species.

Inferences from Mapping

Results of post classification comparison change detection scheme employed to discriminate spatial and temporal invasion of *P. juliflora* between 1986 and 2007 in Amibara District revealed that the invaded land which was 769 ha in 1986 changed to 3,849 ha by 2001 and highly increased to 11,579 ha by 2007 year. During this period, almost all the land-use/land cover has been invaded by *P. juliflora*. Shrub land was the most affected land-use/land cover having 2,742 ha area invaded by *P. juliflora*. Between 2001-2007, the overall change of all other land use/land cover to *P. juliflora* invaded land have showed at least two fold increase than during 1986-2001 period except the cultivated land that was

reduced by half in percent invasion. Hence, the rate of change from other land-use/land cover to invaded land has shown an increasing pattern in 0.06% area per year in 1986-2001 to 0.37% per year of the study area in 2001-2007(Getu 2008).

Management of Prosopis the UNEP/GEF RBIPMA Project

The general objective of the control intervention by the Project was to contribute to the efforts of the government and the local community and strengthen the conservation of biological diversity in Amibara District. The specific objectives were: to assist the community in the District to restore the rangelands through clearing undesirable plants, improving the water facility and reseeding of indigenous and non-invasive exotic pasture and tree species (under irrigated and non-irrigated situations); cultivation of improved crop varieties (for irrigated areas) and identifying, documenting and scaling-up (when ever applicable) the local innovations the communities were/are using to reduce impacts of the change using their own resources and all opportunities coming in the future. Reports hereunder are summarized from the Terminal Report of the Project (Rezene, 2011a) and another separate report on Recommendation for the Management of *Prosopis juliflora* (Rezene et al., 2012).

On Station Activities

Trial plots for the regeneration of native vegetation under various regimes of cleared Prosopis were established close to the Arboretum at Werer Agricultural Research Center (WARC). The treatments comprised "cleared" and "un-cleared" (= controls) and within the cleared plots, there were several different depths at which the main roots of cleared trees were cut: 0, 10, 20, 30 and 40 cm below the ground surface.

The arboretum of trees planned to be used to reforest areas had been fenced and cleared of Prosopis and other weeds and has been protected from livestock and other users. Tree species available in the arboretum include: *Moringa stenopetala, Berchima discolor, Acacia nilotica, Zizipus mouritania,Cordia sinensis, Pithecellobium dulce, Grewia ferruginea, Salvador persica,* and *Azadrichta indica.* Further, nurseries were established to raise seedlings of trees and forage species.All stumped Prosopis coppiced except those stumped at 30 cm and below. Thus, this study was finalized with the remaining plants being removed down to 40 cm below ground surface. After clearing was done Prosopis regeneration through germination of seed took place 2 - 3 weeks subsequent to burning. It was also observed that, the regeneration of Prosopis from the stumped trees and buried stems was very negligible and less compared

to that of growth of Prosopis seedlings from the soil seed bank. This treatment might offer a feasible option for controlling or even eliminating Prosopis from areas where it is not desired. Besides this, introducing and properly manging native tree species in cleared areas and monitoring of the rehabilitated plots indicated that all transplanted beneficial shade, wind break and fence trees and shrubs were established very well with underneath growth of grass and herbaceous species.

On-farm Activities

On-farm activities carried out included: clearing 200 hectare of land from undesirable bushes (*P. juliflora*) using machineries or labor (uprooting the plants with a reasonable depth/20 to 30cm/ not to allow restoring). Clearing of the land was made by participation of the pastoralist communities who were organized in sub-groups and each group took its own share step by step until the 200 ha of land was cleared. In the cleared land one surface water harvesting structure (catchment) was constructed to conserve moisture to support the natural regeneration of grass and herbaceous vegetation on Prosopis cleared rangeland at Alydege. On the same location vertical and horizontal parallel soil structures (terraces) were constructed for harvesting rain water in Prosopis cleared fields for the same purpose. Growth of native herbaceous and grass fodder species including *Acacia nilotica* appeared from the natural seed bank few weeks after the on-set of main season rains.

Scaling-up of Prosopis Integrated Management Technologies

Following a series of trainings and mass awareness creation campaigns by the Project to pastoralists, large scale state owned and private farms have cleared Prosopis from about 10, 000 hectares of land at more than 15 sites of the Amibara District, Tendaho and Dubti areas of the Afar National Regional State including the neighboring localities of the Awash National Park. In this connection a close to 200,135 seedlings of 15 species of native and non-invasive beneficial trees and forages were raised and distributed to communities and collaborative stakeholders for rehabilitation and restoration of lands following clearing of Prosopis.

In the irrigation based Bedulali, Serkamo, Kalatburi and Halay-Somali sub-Districts seeds of maize, sesame, onion including 10,000 sweet potato cuttings and 950 seedlings of mango were distributed with the Project assistance. Technical trainings about field management were given to pastoralists and DAs in the District prior to implementation.

Monitoring of Effects of Control

Vigorous of follow ups done to monitor how biodiversity returned to the areas cleared of Prosopis indicated that native grasses such as *Chrysopogon plumulosus, Cenchrus ciliaris, and Setaria acromelaena* including many herbaceous species in irrigated lands cleared of Prosopis were growing back from the soil seed bank. However, in the moisture stress situations of Halidegie growth of native grasses and herbaceous was seen after the onset of rainfall.

Under the irrigated schemes with protection from livestock and weeds many of native species showed potential for competition with germinating Prosopis seed banks. It was also noted that watering previously un-irrigated woodland helped native tree species seedlings (*Salvadora perscica, Cadaba rotundifolia, Grewa tenax, Acalypha fruticosa, Cordia sinensis, Tamarix aphyella, Phyllanthus reticulaus, Acacia senegal, Acacia tortilis, Acacia nilotica* and *Acacia melifera,*) to grow from the seed bank. This was useful information for the rehabilitation of cleared areas with access to irrigation.

The trial on regeneration of cleared Prosopis and re-appearance of native vegetation in 25 ha of land (near-by to the Lucy Irrigation Engineering Vocational Training Center) that was severely infested with Prosopis continued to show the best methods for control and the range of species were observed returning over time. Initially Prosopis was uprooted using heavy bulldozer machineries acquired from the Awash Basin Authority. Coppices formed few weeks after initial clearing from underground parts of undamaged Prosopis trees were uprooted again using human labor. Follow up had been being done regularly to clear any Prosopis re-growth and the area is now fully recovered and Prosopis effectively controlled.

Management Methods

Management methods employed comprised: integration of traditional mechanical control practices using manual tools and machineries followed by rehabilitation and restoration of cleared fields with crops, forage and tree species as appropriate. Chemical control practices are still under testing process.

Key points to considered in applying any management activities against Prosopis:

- Prosopis is a nuisance in rangelands where it forms dense impenetrable stands, particularly around waterways – hence, main river banks, primary and secondary irrigation canals should be free of Prosopis.

- Animals eat the seed pods and spread the seeds – hence, fields cleared from Prosopis invasion should be fenced to restrict their movements onto the cleared fields.
- Control requires an integrated management approach, including mechanical, chemical and biological techniques and the use grazing strategies.
- Rehabilitation and restoration of invaded sites or areas (*where applicable*) after removal of *Prosopis*.
- When using mechanical control care should be taken to avoid removal of native trees and shrubs, unless a permit has been granted.
- Follow-up control is essential. It requires a monitoring programme done on a regular basis, to ensure early detection and removal of emerging seedlings until the viable invasive seed bank is exhausted and indigenous plants are once again naturally re-establishing.
- Failure to perform the necessary follow-up control and rehabilitation creates an environment in which the cleared land may be revert to its previous, or an even worse, state of infestation.
- Local people participation in *Prosopis* management plan development is critical to ensure effective plan support and implementation.

Chemicals control: Basal bark treatment with glyphosate by spraying all around the circumference of the lower stem(s), up to 750 mm from the ground) was effective and should be used during the moist season conditions (depending on rainfall pattern and location) on mature Prosopis trees. The cut-stump technique, where herbicide is immediately applied to a stump that has been cut horizontally very close to the ground, is effective all year round. Seedlings can be controlled by spraying foliar herbicide over the entire plant. This is particularly effective for dealing with actively growing, dense stands of Prosopis up to 1.5 m tall.

Mechanical Control: Mechanical control techniques, ranging from blade ploughing to grubbing and chaining, were used for removing as much of the root system as possible to prevent the tree re-shooting. Motorized chainsaws were also used for demonstration purposes to cut trees faster than using manual tools. Because a chainsaw is a high-speed wood-cutting tool, some special safety precautions must be observed as with any other power saw to reduce the risk of personal injury. Mechanical control has varying levels of effectiveness depending on the size and species of the plant, but will kill Prosopis if the roots are removed to a depth of 30 cm below the ground surface or more (to remove the bud zone of the root system). If this is not removed, re-shooting can occur.

Ploughs can be used with maximum costs at approximately Birr 2000 per hectare in clearing dense infestations. Controlling Prosopis using 'grubber' attachments on bulldozers and tractors, gave best results in a normal wet season year. However, grubbing is only cost-effective for treating light infestations or small areas of dense infestations – costs exceeded Birr 3300 per hectare in grubbing dense infestation of Prosopis trees. On the other hand, chain pulling used by large-scale farms in the affected areas was found to be the cheapest but least effective control method because of low kill rates. Care is required when using this mechanical control to prevent damage of native species.

Rehabilitation and Restoration: After effective control and eradication the next step must be rehabilitation or restoration of the area. To rehabilitate or restore previous grassland plains to minimize invasive species risk, promote healthy ecosystem components, and support sustainable pastoral activities:

- Collect desirable native seeds from local healthy ecosystems
- Remove all *Prosopis* from targeted management area
- Drill desirable native seeds
- Initiate carefully managed pastoral activities three years after desired species emerge
- Eradicate new *Prosopis* seedlings with appropriate mechanical tools
- Long-term management should consider restoration or deferred grazing

Biological Control: An assessment study on insect natural enemies associated with Prosopis carried out in Amibara District showed that different species of insects which belong to the families Bostrychidae, Curculionidae, Cerambycidae, and one lepidopterous species were observed to feed and produce substantial damage onto Prosopis trees (Shashitu, 2008).

Parthenium hysterophorus

Distribution, Status and Menace

Parthenium hysterophorus an obnoxious alien weed species has spread throughout Ethiopia after its noticeable occurrence in Dire Dawa in 1980. It is found in varying dimensions on waste-lands, along roadsides, railway tracks, cultivated fields, residential areas, industrial areas and other fallow lands as well as abandoned fields. Now it has achieved a status of 'worst weed' in the country owing to its adverse effects on man and animals. Parthenium has several built-in properties and efficient behavioral mechanisms, which enable it to overcome many ecological adversities and thus continue to survive under stress. Hence, in the absence of any effort, parthenium may be able to survive

for comparatively a period longer than what is hitherto recorded with other species (Rezene, 2008; Tamado et al., 2000 and Taye et al., 2009c). The species is introduced into Ethiopia: either through the Djibouti - Dire Dawa railway line or the Dire Dawa Air Port around 1980 (Mesfin, 1991) or as Parker (1989) reported the occurrence of the weed for the first time around Dire Dawa, Harer and Meiso. The occurrence of the weed in south Welo starting from the air - strip in Kombolcha and settlement sites down to Jijiga (Frew et. al, 1996) strengthens the view that the seeds of this species are brought into Ethiopia via the various food aid programs (Mesfin, 1991; Medhin, 1992). Currently the weed is almost occurring in most par of the country with severe ecological, economical and social consequence both in the rural and urban settings. Distribution of *Parthenium hysterophorus* in Ethiopia is presented in Figure 2. From these new foci (mainly roadsides and railway trucks along movement corridors parthenium invades adjacent fields that are used for crops and after harvest for livestock grazing. Parthenium plants are found at high infestation levels both during the crop growing and fallow periods. It is one of the very few green plants found at all growth stages after harvest during dry season. The weed's germination is not tied to a specific time of the year as it can germinate, grow and reproduce throughout the year. In contrast, most native species germinate at the beginning of the rainy season (June – September). Between Parthenium plants, one finds bare soil indicative of the high grazing pressure on fallow lands used as rangeland in this site (Rezene et al., 2004; Tamado et al., 2000; Taye et al., 2009c; and Firew, 1996).

Parthenium has substantial impact in arable land, pasture and grazing land. The occurrence of the weed in grasslands is reported to reduce forage production up to 90% besides making land less fertile; affecting grazing land, animal health, milk and meat quality. Medical and veterinary effects are just starting to come to light in some localities of the country.

Parthenium has become an increasingly serious problem in major crops in eastern part of Ethiopia in addition to being a major problem on range land and waste land. Previous reports indicated that although the prevalence and distribution of the weed was extremely high, the infestation is minimal in arable land. Even then, several hectares of agricultural and rangeland in eastern part of Harerege were infested by this pernicious weed (Frew et. al., 1996).

Parthenium is rarely seen in well cultivated fields. However, its problem persists in poorly managed fields, broad spaced crops, in plantations, and grasslands. The problem is more serious in non-crop areas, neglected fields,

along fence lines, irrigation or drainage ditches and wastelands. While some measures of control is adopted by farmers in farmlands, the problem in wastelands and in public places like parks, roadsides and railway tracks where it is most serious is not tackled by anybody.

Parthenium is having a substantial impact in arable and grazing land in the Welenchiti area (Rezene, 2011b). It is reported to reduce forage production by up to 90%. Sorghum grain yield losses varied from 40-97%, depending on the year and site, if Parthenium is left uncontrolled throughout the cropping season (Tamado et al., 2002). This invasive species is not used as forage nor favored by livestock.

Parthenium clearly poses a major threat to rangelands but may also threaten protected areas, where it is known to be present, if combined with overgrazing. The latter is a likely to occur should prosopis become widespread in the Awash National Park. This will increase pressure on existing grazers. Increased incursion of domestic livestock into the park (under the pressure of prosopis and parthenium invasion) would also result in overgrazing, facilitating parthenium invasion resulting in a positive feedback process of ecosystem degradation and invasion (Rezene, 2011b).

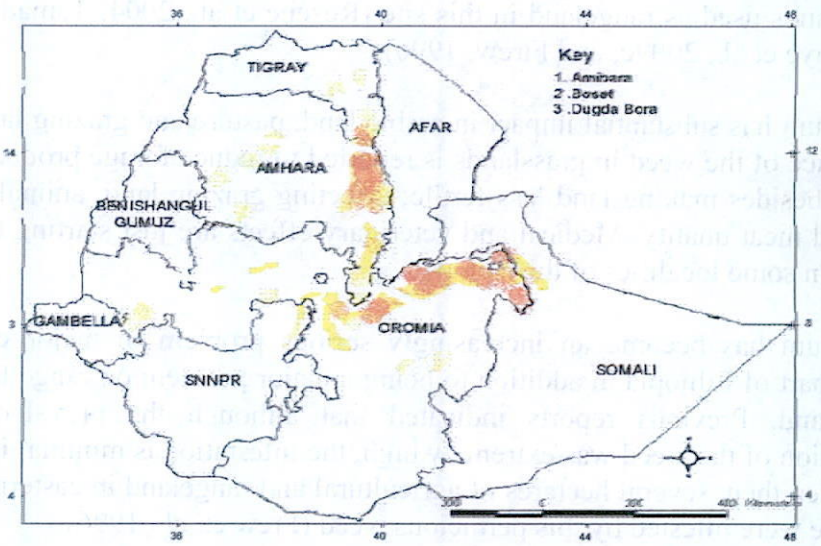

Fig. 2. Distribution *Parthenium hysterophorus* in Ethiopia

Impact assessments

Biodiversity assessment

In a biodiversity assessment study conducted at Welenchitti Parthenium was one of the 5 dominant species in three study in three Peasant Associations (PAs): Xiyo, Digelu and Tiri Birreţi of Welenchiti District (Taye et al., 2007).

Impacts P. hysterophorus on herbaceous plant diversity

The herbaceous plant diversity in the rangelands of Fentale District revealed extremely high frequency, abundance and dominance of parthenium compared to 111 plant taxa belonging to 27 families where Poaceae, Fabaceae, Asteraceae, Euphorbiaceae, Amaranthaceae and Solanaceae were found to be of the highest in species diversity. Parthenium density, percentage cover and heights significantly higher than the other herbaceous plants grown in the area and it was able to cause flora shift from grasses to broad-leaved plants. Greater dry matter yield was also recorded for Parthenium compared to the broad-leaved plants, grasses and sedges. Parthenium seeds recorded from the soil seed bank study accounted for 53% and 80% of the total count in 2006/2007 and 2007/2008, respectively. Overall, these results indicated that parthenium had a negative impact on the grassland species composition and their quantitative characteristics (Mulisa, 2008).

Competitiveness of Parthenium with other Plant Species

Competitiveness of parthenium (*Parthenium hysterophorus*) was determined with other selected plant species (*Argemone mexicana, Cassia tora*, and *Xanthium strumurium*) and also soil nutrient depletion by the respetive test plants. The relative crowding coefficient and aggressivity index values of the test plant species showed that *X. strumarium* significantly out competed *P. hysterophrous* in all parameters i.e. biomass fresh and dry weight, plant height and leaf area at all plant density proportions (i.e. 100:0, 75:25, 50:50, 25:75 and 0:100). Soil analysis result also showed highly significant differences ($p < 0.01$) among samples taken from the root zone of test plant species. The lowest soil pH, total nitrogen, organic carbon, available P and K were recorded from *P. hysterophorus* while the highest were recorded from soil sample before planting. *X. strumurium, A. mexicana and C. tora* recorded more or less an equivalent values for the soil parameters measurement (Kifle, 2009).

Impact on grazing land communities in north-eastern Ethiopia

Lisane et al. (2010) conducted detailed investigation into the impact of *Parthenium hysterophorus* infestation in the north-eastern grazing lands of Ethiopia. Data on the above-ground and seed bank species diversity were

collected from five areas, each having sites with low, medium, or high levels of weed infestation. A total of 72 species was found in all areas.They were categorized into grass species (23), other species (48), or *P. hysterophorus* for ease of interpretation. A regression analysis showed a highly significant, but negative, relationship between the aboveground species diversity and evenness with *P. hysterophorus* abundance. The mean cover abundance for the three infestation levels was 33.4% for *P. hysterophorus*, 41.0% for the grass species, and 26.5% for the other species.The most dominant grass species under all infestation levels were *Cynodon dactylon, Urochloa panicoides*, and *Chloris gayana*, while *Andropogon abyssinicus* and *Eragrostis* spp. were dominant under the low and medium infestation levels, respectively, and *Hyparrhenia hirta* was dominant under the low infestation level. Among the other species, *Solanum nigrum* was the most dominant under the low infestation level and *Datura stramonium* and *Xanthium* spp. were the most dominant under the medium and high infestation levels, respectively. The above-ground dry biomass of *P. hysterophorus* increased between the low and high infestation levels, while that of the grass or other species reduced in the high, as compared to the low, infestation level. Although the grass species density decreased significantly with successive increases in the *P. hysterophorus* infestation level, no such trend could be seen for the other species.

Within the soil seed bank, the viable seed density for the grass species, other species, and *P. hysterophorus* were 25.7, 5.8, and 68.5%, respectively. Similarly, the soil seed bank under the low-, medium-, and high-infestation sites was dominated by *P. hysterophorus*, which contributed 25.1, 65.4, and 87.4% of the viable seed bank, respectively. Although the overall similarity between the above-ground vegetation composition and the soil seed bank was low, it was similar at the low-infested site. Thus, the invasion by *P. hysterophorus* was found to critically endanger the biodiversity of the grazing lands, particularly for the different grass and forbs species in the area. These changes might adversely affect not only future agriculture, but also food security, unless appropriate practices are developed and implemented for *P. hysterophorus* management (Lisane et al., 2010).

Impacts on food production, plant biodiversity and human health

The weed has invaded a variety of habitats ranging from roadsides to grasslands and crop fields. Infestations were found to be greater than 20 plants per m^2 and yield losses in sorghum reached 46-97% depending on the location and year. In grasslands dominated by parthenium, native plant species composition and abundance was found to be low. Manual control of parthenium by farmers

resulted in the development of skin allergies, itching, fever, and asthma. These reactions could be attributed to the presence of secondary plant compounds (parthenin, chlorogenic acid, isocholorogenic acid, vanilic acid and caffeic acid) which were found in parthenium with significant variation in their concentrations among the different plant parts, dependent on plant locality, moisture content and plant size. The social cost of parthenium in Ethiopia was measured by Disability Adjusted Life Years and its equivalence in terms of monetary value was estimated at US$ 2,535,887 - 4,365,057. More resources have to be invested to tackle the parthenium problem as the estimated loss is disproportionate to the cost of investment in parthenium research and development activities (Taye et al., 2009b).

Assessment of Parthenium Compost

This study was conducted to evaluate the effects of effective microorganism (EM) based *Parthenium hysterophorus* L., compost on growth and development of tomato and tef. The treatments were EM treated parthenium compost, EM untreated parthenium compost, EM treated locally available plant material compost, EM untreated locally available plant material (conventional compost), recommended rate of nitrogen and phosphorus fertilizer, half recommended rate of NP fertilizer plus half rate of EM treated parthenium compost, and untreated check. Generally the experimental result revealed that dual benefit has insured from uprooting of parthenium. The inclusions of EM improve the conditions of and all other sources of composts. Growers can utilize the biomass of parthenium induced with EM as organic source to obtain remarkably higher yield compared to the conventionally prepared compost. Moreover, the combination of half the rate of NP fertilizer plus half the rate of EM treated parthenium compost gave statically equivalent parameters of growth compared with NP fertilizer. This implies that, use of the combinations found cost effective since half cost that would have been incurred to purchase NP fertilizer is reduced.

Investigation of pathogens as biocontrol agents

Surveys to determine the presence and distribution of pathogens associated with parthenium and further evaluation of the pathogens found as potential biocontrol agents.. Several fungal isolates of the genus *Helminthosporium*, *Phoma*, *Curvularia*, *Chaetomium*, *Alternaria*, and *Eurotium* were obtained from the seeds and other plant parts. However, all of the isolates tested were non-pathogenic except *Helminthosporium* isolates. The two most important diseases were the rust, *Puccinia abrupta* var. partheniicola and the phyllody, caused by a phytoplasma belonging to the species "*Candidatus Phytoplasma aurantifolia*".

Host specificity tests revealed that the rust, *P. abrupta*, only sporulates on parthenium while the phyllody infected parthenium, groundnut, sesame, grass pea, lentil, and chickpea. Suspected insect vectors were examined for phytoplasma infection by means of Polymerase Chain Reaction (PCR). The successful acquisition of phytoplasma's by the leafhopper, *Orosius cellulosus* Lindberg (Cicadellidae), was determined by molecular detection of phytoplasma. Phytoplasma was also detected from a single bait plant after feeding by the leafhopper. Sequencing data from phytoplasma obtained from parthenium and the above mentioned crops was identical with sequence identities > 98%. The rust was commonly found at 1400 – 2500 m.a.s.l. with disease incidence up to 100% in some locations while phyllody was observed at 900 – 2300 m.a.s.l. with incidence up to 75%. Individual effects of the rust and phyllody diseases on parthenium in different locations under field condition showed significant reduction on seed and morphological parameters. Seed production was reduced by 42 and 85% due to rust and phyllody, respectively (Taye et al., 2009a).

EIAR and IPM/CRSP VSU, USA cooperative research programme
Biocontrol of Parthenium

Activities are underway by USAID supported project "Abating the weed parthenium (*Parthenium hysterophorus* L.) Damage in Eastern Africa Using Integrated Cultural and Biological Control Measures" implemented by IPM/CRSP VSU, USA in collaboration with Ambo Plant Protection Center of the EIAR to release a beetle *Zygogramma bicolorata* in selected pockets of Boset District for controlling parthenium. Preliminary evaluation of the beetle in laboratory conditions shows encouraging results but its effectiveness in field conditions is yet to be ascertained. The safety of *Zygogramma bicolorata* to non-target plants was tested on a total of 17 crop species and 10 n0n-crop species under quarantine at Ambo PPRC. In addition the beetle was tested on 5 niger seed (*Guizotia abyssinica*) varieties, on tef (*Eragrostis tef* and on two sunflower (*Helianthus annuus*) cultivars in Ethiopia. Like Parthenium both niger seed and sunflower belong to the family Asteraceae but tef is in the family of Poaceae. Host range testing conducted under quarantine in Ethiopia on the above economically important crop species and varieties and indigenous species, established that *Zygogramma* is safe for release against parthenium (Kassahun, 2012).

Distribution map of Parthenium

CLIMEX modeling indicated that Ethiopia, Kenya, Somalia, Tanzania and Uganda in eastern Africa and South Africa, Swaziland, and Mozambique in

southern Africa as well as the south of Madagascar are ecoclimatically suitable for the favorable growth of *Parthenium hysterophorus*. Distribution survey data for Ethiopia and southern Africa were compiled into a database and mapped and the weed was shown to be much more widespread than previously recorded. Actual distributions determined during road surveys concurred with CLIMEX predictions, validating the model. There are still areas that are highly suitable for parthenium growth that have not yet been surveyed (Kassahun, 2012).

Management /Control of Parthenium: (Lessons from the UNEP/GEF RBIPMA Project)

Initially the control of parthenium was felt rather difficult, primarily due to its invasive nature, strong reproductive and regenerative potential. The mass awareness and community participation was very important to deal with the parthenium problem in both urban and rural situations. The formation of Action groups on parthenium under the Pilot Site Management Committee was essential at District and sub-District level. Reports hereunder are summarized from the Terminal Report of the Project (Rezene, 2011b).

The integrated management system for parthenium adopted was amalgamating more than one control option applied based on the habitat of parthenium infestation (different crop types, roadsides, grasslands, wastelands and rural urban settings); category of the infested areas (where the plant must be destroyed, reduced or prevented), involving prevention of spread or establishment, manual and mechanical control, use of indirect weed control methods (agronomic practices), and herbicide use depending on the above indicated situations. Individual model farmers and urban dwellers were rendered responsibility to eliminate the Parthenium plants establishing in their surrounding. For ensuring special attention on the intervention control programs two District level Community / Public Awareness Campaigns were launched by the project during 2007 and 2008 in collaboration with Government and Voluntary organizations (NGO's) and active public participation.

Crop Situations

Forty five crop specific demonstration plots for Parthenium management were established in 43 ha of three model sub-districts at Welenchitti pilot site (Tiyo 7.5 ha; Tri Bretti 19.5 ha and Degelu Wanga 16 ha) for three consecutive crop seasons 2007 - 2009. Test crops used were maize, sorghum, wheat, tef, haricot bean and maze/haricot bean intercropping. Control options were developed and scaling-up of effective integrated management technologies undertaken.

Concerted integrated efforts including physical, mechanical and chemical methods were employed throughout the 3 years intervention program for its effective suppression in the marked areas.

Throughout, with the onset of rainfall, repeated shallow cultivation with the local oxen plough helped to destroy newly emerging seedlings and at the same time, gave favourable conditions for germination of the seeds on the upper soil surface and consequently exhausted the weed seed bank. In cultivated land, highly competitive crop varieties coupled with regular cultural practices along with the following specific recommended herbicides were used for its suppression:

Wheat and tef: Post-emergence herbicides: 2, 4-D Amine Salt 720 g/l @ 1.0 l Prod. /ha; Fulorxypir 200g/l ae EC @ 1.0 l prod. /ha; Flurasulam 75g/l + Flumeusulam 100 g/l SC @ 0.05 + 0.07 l/ha; Flurasulam 6.25g/l + 2, 4-D 300 g/l @ 1.0 l/ha; and Aminopyralid 300 g/kg + Flurasulam 150 g/kg WG @ 30 + 33.3 g/ha including twice hand weeding (applied 30-35 + 55-60 days after sowing (DAS); and untreated weedy check. Non-target grassy and broadleaf weeds were removed by hand pulling as necessary in occurrence.

Maize: Pre-emergence herbicides: s-Metolachlor 290g/l + Atrazine 370 g/l SC @ 4.0 l Prod. /ha; Inter-row oxen cultivation or hand hoeing at knee height followed by 2-3 hand weeding as necessary.

Sorghum: Atrazine 500 g/l FW @ 4.0 l Prod. /ha; Inter-row oxen cultivation or hand hoeing at knee height of maize followed by 2-3 hand weeding as necessary.

Maize haricot bean intercropping: Hand hoeing at knee height of maize followed by 2-3 hand weeding as necessary.

In all demonstration fields irrespective to crop species non target grassy and broadleaved weed species were removed by hand pulling as necessary in occurrence. As per the directives of the parthenium Action Group every one was obliged to keep their farmland surroundings clean of Parthenium.

Non-crop Situations

Occupier of any land where parthenium grows was directed to take preventive and curative measures. It was the responsibility of the communities in the model sites to prevent the growth of Parthenium through out the year in fallow,

wasteland, grazing land and roadsides including in and around their living places. It was here that village community, the Welenchitti city council, agricultural development agencies, NGOs, including elementary and secondary school students and other voluntary groups organized to participate for the success of the intervention program. Programs were being started with action plan and wide publicity by the parthenium Action Group for 3 – 4 times in a year under soil wet situation at onset of the short and main rain seasons. In all cases, parthenium plants were uprooted to prevent regeneration from the remaining lateral shoots and such operations were done before flowering and when the soil is moist enough to facilitate easy removal.

Monitoring of Effects of Control

Results of the above concreted activities created an excellent and rapid public awareness and cooperation to control the weed and to expand the capacity to adopt community agreed-upon legal steps to minimize the spread of parthenium in Boset District. The extent of parthenium in the rural and urban settings of the control intervention model demonstration areas has been significantly reduced; all known roadside infestations have been suppressed and all known infestations on private land are under active control.

Despite the short period activities, an estimated 60 -70% of the parthenium infestation was brought under control in major infested area (38 sub districts) and totally eradicated (4 sub-districts) from the isolated patches in 2005. However constant short-term activities are needed to keep the parthenium population at low level until an effective self-sustained biological control programmes become a reality.

Inter-row oxen cultivation or Hand-hoeing twice followed by twice hand weeding in (maize and sorghum) and twice hand weeding applied during early and mid crop growing periods in (wheat and tef) consistently suppressed Parthenium weed. The time and condition for hand weeding is similar to non-crop situation.

The selective post-emergence herbicides: 2, 4-D Amine Salt 720 Fulorxypir 200g/l ae EC Flurasulam + Flumeusulam 175 SC Flurasulam 6.25g/l + 2, 4-D 306.25; and Aminopyralid + Flurasulam 450 WG were effective as manual uprooting to control the previous flush but did not persisted long to control the subsequent flushes and necessitated 1- 2 supplementary hand weeding to keep the fields free of Parthenium up to crop harvest.

Pre-emergence residual herbicides: s-Metolachlor + Atrazine 660 SC and Atrazine 500 FW effectively controlled parthenium along with other annual weeds in maize and sorghum respectively and re-growth of parthenium was not observed up to 3 months.

As a whole, the control intervention by the project in the 54 model demonstration plots had been the success story of this noxious weed management. Lessons learnt from these participatory control interventions clearly demonstrated that all the above techniques involving prevention of spread or establishment, manual and mechanical control, use of indirect weed control methods (agronomic practices), and herbicide use should be adopted simultaneously in an integrated manner so that the spread of parthenium and its harmful effects could effectively be reduced.

Communities participatory demonstrations

The effective manual and chemical technologies were demonstrated on large scale (100 ha for wheat and tef) in Tiyo 30 ha; Tri Bretti 40 ha and Degelu Wanga 30 ha) in integrated manner with farmers participation. Other 650 farmers and 25 extension workers from Boset and Adama Districts were made aware of the same by organizing field days.

All these studies revealed that this weed can be effectively managed with integrated approaches on campaign basis with the participation of all concerned government institutions (extension and research); NGOs and communities in the affected areas.

Alien Weed Invaders in Aquatic Ecosystems

Wetlands, lakes and rivers, have been impacted by alien invasive plant species that specialized on aquatic (and semi-aquatic) systems. Worldwide, the damage caused by alien invasive plant species to wetlands runs into billions of dollars annually. Further are the huge cost of control, to manage the invasive species and then to restore the affected ecosystems to their previous condition – these also run into many millions of dollars per year (Howard and Matindi, 2003). Due to lack of extensive survey studies only few species are reported to be as potential alien plant invaders in the aquatic ecosystems of Ethiopia. Among these, the most important one is water hyacinth (*Eichhornia crassipes* [Martias] Solms), which has inflicted many of enormous damage to Ethiopia's wetlands - lakes, rivers, hydropower schemes, irrigation and water supply schemes, fisheries, aquatic biodiversity and human-welfare (Stroud, 1994; Rezene, 2005 and 2011c; Senait et al., 2007; Firehun et. al., 2007; Dula et.al., 2008; Daniel,

2008 and BDU/ARARI, 2011). The rest potential alien aquatic weed invaders are: *Pistia stratiotes*, *Rorippa nasturtium-aquaticum* and *Mimosa pigra*. The status of water hyacinth in Ethiopia and what is being done to tackle this problem are summarized as follows:

The status of water hyacinth in Ethiopia

In Ethiopia this weed was officially reported in the year 1965 in Koka dam and Awash river. Although the infestation was small the earliest observation of water hyacinth was reported in Dugda Bora district between the year 1949 to 1958 (Stroud, 1994; Rezene, 2005). Infestations of water hyacinth in Ethiopia have also been manifested on large scale in many water bodies of the country, in Gambella area (Sobate, Baro, Gillo, and Pibor Rivers); the Abay River just south of Lake Tana, Lake Zeway and Lake Ellen in the Rift Valley (Stroud 1994 and Rezene, 2005). Before 1958 water hyacinth had never been reported in the Upper Nile Region. By 1962 the plant had succeeded in infesting the whole stretch of the White Nile from Juba to Jebel Aulia Dam; the whole length of the Sobat River from its mouth eastwards up to Baro and Gillo Rivers in Ethiopia and southwards up to Pibo River to Akobo. The Baro River is the main transportation route between South Sudan and the River port of Gambella. Difficulties experienced by steamers and boats since the advent of water hyacinth have been frequently reported (Rezene, 2005). Other than these, there were no known records of water hyacinth in Ethiopia particularly in the upper basin of the Abay River until the recent survey report released by a Team of Experts in the Amhara National Regional State revealed its occurrence in Lake Tana (BDU/ARARI, 2011). Distribution of water hyacinth in Ethiopia is presented in Figure 3.

Water hyacinth in the Awash River system and Rift Valley Lakes

The introduction and rapid spread of this plant in the Awash River system has produced serious problems for the use of the river as a source hydropower by blocking the water intake points, which forced the power generation to be periodically closed down in order to clean out the weed (Stroud 1994). Some clean - up attempts have been made during 1959, 1968, 1979 and 1988 to remove the weed using human labor, and while pursuing this technique acquired moderate control at considerable cost. Sooner the physical removal of the weed was stopped and massive re-infestation occurred between Aba Samuel wetlands (not primarily in the Awash drainage but connected to it during the flood season); Lake Ellen (assumed to be the original source of water hyacinth) and the Koka Lake. Aba-Samuel wetland which is the extreme end of the upper stream is enriched by Akaki river, in which almost all types of wastes of Addis

Ababa city have been damped. Farmers in the area reported that foreign inhabitants residing near the wetland introduced water hyacinth to the water body from the nearby Lake Ellen (Senait et al., 2007). In these areas, notably in the vicinities of Lake Ellen and around the bridge crossing the Mojo Awasa Highway near the town of Alem Tena, mats of floating plants are always observed stranded on banks and shorelines when the water level falls and they float again when the water level rises (Rezene, 2005). Senait et al., (2007) reported that except Lake Ellen (8 km North of Alem Tena town) and Koka dam, other rift valley Lakes: Ziway, Langano, Abiyata, Shala, and Awassa were proved to be free from water hyacinth, but the risk (potential) for their infestation was still there (Rezene, 2005). Currently, water hyacinth has succeeded in infesting Lake Abiyata leading to potential threat to the whole stretch of the rest of important water bodies in the central and southern rift valley aquatic ecosystems of the country. Further survey report in the Awash River System by Firehun et. al. (2007) revealed that in the Ethiopian Sugar Estates, the weed was restricted to Wonji-Shewa and Metahara. In Wonji-Shewa, water hyacinth was first introduced from Koka Hydroelectric Power Dam because of the 1996 flood of the Awash River in the Factory.

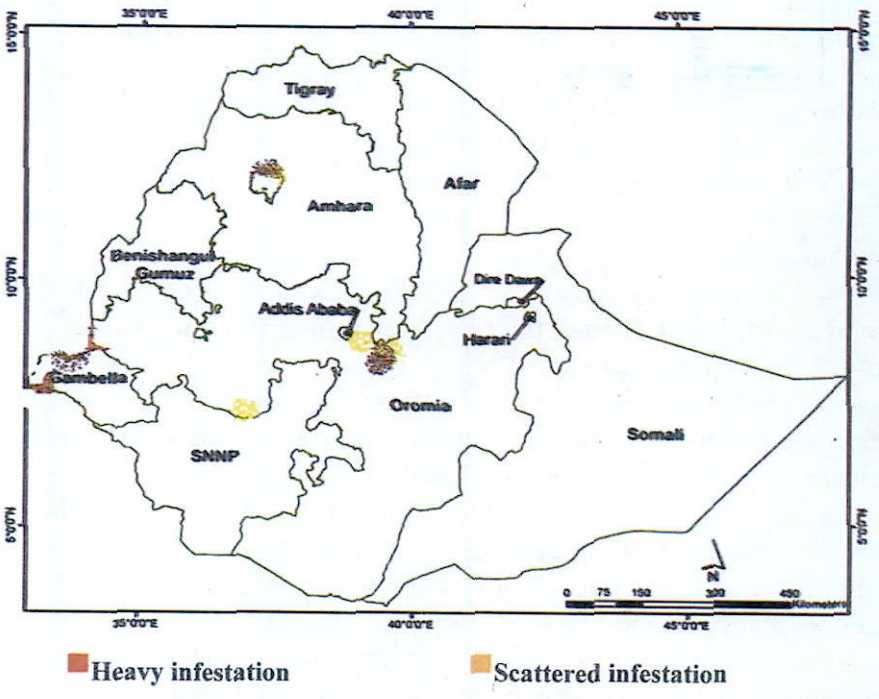

Fig. 3 Distribution Water hyacinth in

Determination of spatio-temporal differences of water hyacinth and its effect around Aba Samuel Lake using RS and GIS was also studied by Abraham (2008). Satellite images of 1986, 2000 and 2005 with satellite path 168 and row 054 were used for the analysis. Digital image classifications as well as change detection were carried out with over all accuracy of 84% and the finding of these analysis shows that water hyacinth have changed spatially and temporally over the time in the study area. At the beginning of the study period (1986) the water hyacinth were located on the northern part of the lake but in later periods it was concentrated mostly on the southern part of the lake. Water hyacinth increased over time from 1986 (0.7 %) up until 2000 (5.0 %) afterwards it started to decline 2005 (1.8%). The change detection analysis shows that the lake environment was subject to more changes in cover types over time than other classes; and farmland exhibits the highest changes in terms of increase in area or in hectare. The drivers of water hyacinth expansion were also assessed. Temperature and nutrient level were among the factors that enhanced water hyacinth establishment on the lake. Temperature increases and variations were observed on the study area. It was determined that different land cover types have shown different temperature attributes. Nutrient level on the lake shows high load and is beyond the limit as a result it has polluted the reservoir and caused eutropication. The NDVI values where water hyacinth found in high density and temperature attributes of the same location were assessed and the correlation was strong and was inversely related. And similar assessment was made for NDVI values where water hyacinth found in high concentration and the Nitrogen level of the same location and the correlation was less strong and the two were directly related. From this assessment it can be said that even if temperature and nitrogen are essential factors for plant growth temperature appears to be the determinant factor for water hyacinth expansion. The existence and expansion of water hyacinth on the lake has an impact on the lake ecosystem biodiversity by reducing fish stock, migratory birds and socioeconomic problem by increase in trend of malaria cases.

Water hyacinth in Lake Tana: (a potential threat to the Lower Nile Basin)

Though the incidence of water hyacinth was reported in Abay River just south of Lake Tana (Stroud, 1994) its potential problem to the water resources was not noted until the survey report released by a Team of Experts in the Amhara National Regional State which revealed its occurrence on the northern shores of Lake Tana (the upper basin of the Abay River) in September 2011. The presence of water hyacinth was confirmed in the area between rib river mouth, Mitreha Abaworka kebele, Gonder Zuria Woreda (GPS reading in units of Utm:0347970 N,13415225E) and Dirma river mouth, Dembia Woreda

(Utm:0316186N,1356528E). The weed was observed in river mouths, where the nutrient condition was relatively good and the water quality condition is deteriorated. The weed on the average had a density of 192 individuals per m^2 and the estimated biomass can reach 450 tons per hectare and double its biomass within 6-15 days According to the interviewed local people, the weed had happened in the area between 1-3 years and neither the local people nor the expedition group was able to trace the source of the weed (BDU/ARARI, 2011).

Negative impacts of water hyacinth in Ethiopia

Local estimates of economic impacts of water hyacinth in most affected areas of Ethiopian water bodies are unavailable. Further, less documented information in this aspect are the impacts of the invasions on water loss, water quality, biological diversity and ecological integrity of the aquatic ecosystem. In the affected areas reported so far, the weed obstructs electricity generation, irrigation, navigation, and fishing; increases water loss resulting from evapo-transpiration; and facilitates proliferation of such diseases as malaria and bilharzias. Limited studies to establish its negative impact at Wonji indicated that the weed inflicted multifaceted problems: such as excess water loss, estimated to be 393,660 to 2,945,160 m^3; restricting water flow, and incurs a control cost of more than Birr 130,197 (USD 14,897) (Firehun et. al., 2007 and Dula et.al., 2008). Another study conducted at Aba Samuel Dam in the outskirts of Addis Ababa near Akaki town revealed that the maximum transpiration of water hyacinth as much as 9.26 ± 0.26 $mM/m^2/s$ (millimole per meter square per second) was measured during dry season. By considering the LAI of the plant at Aba Samuel wetland, the plant loses (transpires) 18.57 and 12.33 mm of water per day in dry and wet seasons, respectively. The evaporation in dry and wet seasons was 5.32 and 2.54 mm per day, respectively. Therefore, transpiration of water hyacinth exceeds evaporation 3.49 to 4.85 times in dry and wet season, respectively (Daniel, 2008).

Virtually all government sectors in the vicinity of the water hyacinth problem area of the Awash Basin consider the weed as a problem. These include fisheries and plant protection departments of the federal and regional bureaus of agriculture, agricultural-research services, environmental and water resources development authorities, large-scale irrigation based agro-industry enterprises and various non-governmental organizations. But, there are no organizational structures in place that could handle the problem due to lack of prompt recognition of the potential hazards. All in all, the response of these

organizations to the water-hyacinth issue still remains to be deficient (Rezene, 2011).

This noxious weed is now abundant along 40 km of the northern and north-eastern shoreline of the Lake Tana, posing a significant threat to livelihoods, biodiversity and tourism. "In 2011 the fishing industry totally collapsed affecting thousands of fishing communities who are dependent on this natural resource, according the press release by EIAR et al. (2012). A reduction in water levels during the dry season caused large amounts of the water hyacinth to die. The decomposition of the water hyacinth caused massive algal blooms which affected the taste of the fish with the result that fisher folk were unable to sell their catch."

Management /control of water hyacinth

Manual and mechanical approaches to managing and controlling infestations of water hyacinth include the use of physical barriers. Such approaches are the most effective and quick, but also expensive and difficult to organize and sustain. Chemical control can also be quick; it has been successful at Wonji, Ethiopia, for example (Dula et. al., 2008). But its management demands more skill, and may have environmental concerns for other wetland biodiversity. The preferred and self-sustaining option is biological control, using the weed's natural enemies. Biological control alone, however, is not always effective and there are often good reasons for using integrated control involving mechanical and chemical control as well.

Water hyacinth has been effectively controlled from 116 ha of water reservoirs and 15 km of primary and secondary canals of Wonji/Shewa sugar plantations by draining all the water reservoirs and burning the accumulated dried herbage on the reservoirs floors after glyphosate application. The seed bank in the top layer of the soil was removed using heavy machineries. Refilled reservoirs and irrigation canals are being monitored to ensure that no infestation occurred (Figures 1 and 2) (Dula et. al., 2008).

Biological control is seen as one of the most sustainable and integral component of reducing the threat of water hyacinth in Ethiopia in the future. In a study conducted during the year 2008 to identify native fungal antagonists associated with water hyacinth and investigate their controlling potential as bioagents against water hyacinth, 19 fungal species were identified among which, nine species with better virulence were selected. Further pathogencity test was carried out in to select the best candidates and five of them were found to be

virulent to water hyacinth with disease severity ranging from 4.33 to 5.67 in 1-6 disease severity rating scale. The five promising candidates were *Alternaria alternata, Ascochyta chartarum, Fusarium chlamydosporium, Fusarium equiseti* and *Pythium ultimum.* The highest disease severity 5.67 was recorded by *Pythium ultimum* while the least severity with 4.33 was recorded by *Ascochyta chartarum.* Results of host specificity test carried on fourteen crops and one weed species revealed that two fungal species (*Alternaria alternata* and *Pythium ultimum*) were found to be host specific, while the other isolates showed wide host range. On this basis, it was concluded that, *Alternaria alternata* and *Pythium ultimum* could be used as effective and safe bioagents against water hyacinth following performance of further evaluation under natural environmental conditions (Samuel, 2009).

Release of biocontrol agents is also being considered to be used as integral component of the mechanical and chemical control. In collaborative activities between EIAR and the Ethiopian Sugar Corporation Research Directorate at Wonji, two weevils (*Neochetina eichhorniae* and *N. bruchi*) have been introduced from Uganda by the UNEP/GEF RBIPMA Project of the EIAR and are currently in mass rearing stage in lathouses at Wonji and release of these biocontrol agents is proposed in the nearby neighboring localities of the Koka Lake area after getting approval from the Federal Environmental Protection Authority (Rezene, 2011c).

Management of water hyacinth in the Awash River System

In the case of the Awash River System, the Aba Samuel dam is still likely to be one of the main source and cause of water hyacinth downstream spread in the Awash Valley (with all its associated irrigation schemes and conservation areas). So some form of control is definitely needed for sustainable WH management in the Awash River System.

Manual and mechanical approaches already proven effective at the Project sites to managing and controlling infestations of water hyacinth include the use of physical barriers. Such approaches are usually the most effective and quick, but they are not affordable by resource deficient communities and call more support from the government and donors. Chemical control can also be quick; it has been successful at the pilot site. But its management demands more skill, and environmental concerns still impedes its acceptance. The preferred option is biological control, using the weed's natural enemies imported from Uganda and are now being tested for mass rearing under local conditions. This is environmentally safe; but it may take time to establish. The ideal would be an

integrated water-hyacinth management, one that makes prompt and judicious use of individual control methods while taking into account the specificity of the infestation.

Rapid response recommendations on management of water hyacinth in Lake Tana

Implementation strategies

- A first step is to make aware the Ethiopian Government of the existence of water hyacinth in the aquatic systems of the Lake Tana, and its potential threat to the whole water bodies and development investments (vast hydroelectric and irrigation schemes including the Great Renaissance Dam in the down streams of the Blue Nile Basin.
- Establish national institutional structures for handling the water-hyacinth problem, with linkages at both federal and regional levels.
- Assign responsibility for water-hyacinth control to a National Apex-Body to be based in appropriate federal ministry, but maintain full and effective liaison with other mandatory government departments, institutions or organizations, and communities of the affected aquatic ecosystem.
- Next is the need to decide at national level what general course of action to take including among others.....
  - Assessing the size of the problem in terms of area (or volume) and the likely impacts of developing invasion.
  - Preventing the invader from establishing or from spreading. This will require weighing up of costs, benefits, side effects of control results of no action, traditions, changing needs and political and policy matters.
  - Management objectives for the control should be agreed upon so that the interests of all stakeholders are considered and the restoration of both human needs and biodiversity are reflected on.
  - Enhance this effort, at national level, with public-information and public-awareness campaigns, including reference to reports on the social, economic, and environmental consequences of water hyacinth.

Policies and Guidelines

- Develop guidelines and policies to improve the response of riparian programs to the water-hyacinth problem at federal and national regional levels.

Coordination of Control

- Establish effective mechanisms (both at federal and national regional levels) to coordinate and systematically implement control efforts and to help

resolve any conflicts arising among stakeholders because of diverse interests.
- Identify stakeholders (both at federal and national regional levels) and secure their full participation.

Communication
- Ensure effective communication between the coordination structures and key stakeholders (because water-hyacinth problems are cross sectoral, the stakeholders within a national program should have effective channels of communication).

Establish effective communication channels for exchange of information between federal institutions, national regional states sharing water bodies in the whole Blue Nile Basin.

Other alien and native invasive plant species

Other alien or native invasive species recorded as threats are *Lantana camara*, *Acacia* spp. and the widely distributed genera of parasitic weed species. . Recent survey records also revealed the introduction and spread of 'emerging plant invaders' such as: *Cryptostegia grandiflora, Parkinsonia aculeata, Mimosa diplorotricha,* and *Nicotiana glauca.*

Lantana camara

Lantana camara from South America, steadily spreading across Africa; uncontrolled despite its status as "noxious", excludes other species, competes for light, space, water, nutrients and is poisonous to some herbivores (Matthews and Brand 2004).

Lantana has usually been deliberately introduced into various localities in Ethiopia (particularly urban settings) as an ornamental shrub, and has been quickly spread by birds and animals that eat its fruits but cannot digest the woody seeds. There are also indications that seeds of lantana are water borne as young plants of this species are observed to escape from drainage ditches in the outskirts of Debre Zeit, Nazret, Harer and Dire Dawa. Hot spot areas of lantana are reported to be in eastern Harerghe and neighbouring localities of the Somali region forming impenetrable thickets in waste areas, abandoned cultivation, grasslands and pastures. In the problem areas lantana quickly take over valuable grazing lands and its dense growth suppresses grasses and other useful forages (Rezene 2005).

There is not much awareness of this problem locally. But, as reported elsewhere outside Ethiopia, lantana is relatively unpalatable and many varieties of the plant are poisonous to stock, causing loss of appetite, frequent urination, dehydration, and yellowing of inner mouth and eyes as liver functions are disturbed. Hairs are lost from the skin, the mouth and eyes smell and ulcerate, and animals may die with one or four weeks. The fruits are also poisonous to children. Lantana is serious problem in forestry and orchard operations, and can be also a problem through increasing fire frequency and intensity in drier seasons. In some areas, lantana thickets provide a breeding ground to tsetse flies, which transmit the parasitic trypanosomes that cause an animal form of sleeping sickness (Matthews and Brand 2004).

Little else can grow on lantana thickets because the plant releases chemicals into the soil to prevent other plants from germinating. The absence of under storey community to provide groundcover resulted in increased erosion, particularly on steep slopes. By excluding other species the thickets reduce plant biodiversity and change the composition of associated animal communities. Lantana is able to spread rapidly once introduced to an area as the seeds are widely dispersed by birds eating the fruit, and are sometimes also washed from infested areas during floods, causing sudden invasion downstream (Matthews and Brand 2004).

Conclusion and Recommendations

Parthenium and Prosopis

The invasions of both Parthenium and Prosopis are widespread in Ethiopia and damaging to the economy, livelihoods and biodiversity. Parthenium seems to have spread or be spreading to most areas of the country and is rapidly becoming a national issue. For this, it is suggested, a national strategy is required. Such a strategy would require endorsement of the higher authorities at federal and regional levels as well as support from the major stakeholders in biodiversity management, agriculture, forestry, livestock production and rural development.

General management to reduce the impacts is also localized and as the plant spreads, so do its negative impacts on people and their health, livestock, cropping and general food security. This will eventually be true of native biodiversity as well, as there is no reason to believe that Parthenium will not reach all of the areas in Ethiopia where it can thrive, which is a large proportion of the country.

Parthenium will cross international borders and so will likely spread southwards and westwards – and possibly through neighboring countries to the southern and central African regions (although it is already recorded in several places in Kenya and Somalia). Thus there is a regional (in the sense of IGAD and EAC) perspective to the management of Parthenium as well as a national one. Such a strategy should aim at reducing further spread and establishing sustainable management on a national scale.

The same is true on a less-wide area for Prosopis where communities have been unable to put their capability to work as they are approached by different firms or for that matter donor driven initiatives done without coordination or communication, often with different or conflicting objectives - with some groups requesting eradication, some proposing control, some wanting zoning and some seeing this invasive tree as their main source of livelihood. In particular, the NGO's driven "*use based-control*" technologies claimed to be available for potential uses had aggravated the spread of *Prosopis* at an alarming rate and are ineffective to be considered as integral components for preventing and managing the *Prosopis* problem. This topic has been discussed for several years and there are already plans for national discussions to develop an agreed strategy for Prosopis management. Such a strategy will, like that for Parthenium, need to be backed by policies, regulations and laws so that it can be implemented to comply with national priorities and local needs.

Water Hyacinth

The existing situation reveals that water hyacinth still remains to be a potential danger to all water bodies with significant economic and development importance in Ethiopia and it is expected that economic consequences may soon become extremely serious. The Government of Ethiopia should therefore, opt for immediate action to control the weed as the cost of doing nothing now would result eventually into enormous economic loss to the country.

Alleviating the Potential Risks of Invasive Alien Species Promoted for Biofuels

Some steps planners & decision makers, investors and researchers should definitely consider whilst dealing with biofuels include: (i) selection of low risk species with regards being or expected to be invasives, and this would require a full risk assessment to evaluate the risk of invasion of species considered; (ii) preparing and importantly implementing risk management including monitoring and contingency planning in proposal for biofuel planning. Control procedures of any cases of "escape" have to be viable, and (iii) use of native species as

much as possible. This will however never entirely prevent the potential of species becoming invasives and a better policy would be to fund alternative sources of energy not using biofuels plants with the risk of invasive species and its huge and long-term impacts to the environment and the economy.

Recommendations on Legal Issues for Invasive Alien Species Management

One of the main stumbling blocks in effective invasive alien species management in this country is the presence of gaps, overlaps and inconsistencies in existing policies, regulations and strategies.

Although it is not considered possible to change legislation shortly, necessary changes are being facilitated by maximizing 'buy-in' from local expert studies coordinated and led by the Ethiopian Institute of Agricultural Research through a GoE – UNEP/ GEF Removing Barriers to Invasive Plant Management in Africa (RBIPMA) Project by targeted and extensive stakeholder input. This has largely been achieved with the development of: National Invasive Species Strategy and Action Plan (NISSAP), and the following five other supporting policy documents and invasive species-related guidelines that can create an impetus for the establishment of National Invasive Species Council and integration of invasive species issues into the strategies that guide the transformation and development plans in Ethiopia:

- National Invasive Species and Strategies and Action Plans (NISSAP);
- Cost Recovery Mechanism Procedures for Invasive Species Management;
- National Invasive Species Communication Strategy;
- Risk Assessment, Early Detection and Rapid Response Procedures for Invasive Species Management;
- Generalized Training Modules for Invasive Species management
- Guideline for Integrating Invasive Species Issues into Curricula of Learning Institutions.

Two national stakeholders workshops convened to review the aforementioned policy documents in September 2010 made specific recommendations to EIAR to continue as a focal point of the national Invasive Species management and serving as the Secretariat of the National Council of IAS planned to be established under the chairmanship of the Ministry of Agriculture as well as supporting research for development activities focusing on sustaining all initiatives of the GoE-UNEP/GEF RBIPMA Project.

Thus, endorsement of the aforementioned NISSAP and other supporting policy documents and invasive species-related guidelines by the Government through the appropriate Ministry is very crucial in alleviating the devastating impacts of invasive species in Ethiopia.

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Summares of the general discussions on the IAS (*Chaired by Dr. Ferdu Azerefegne and rapportuered by Dr. Melaku Alemu*)

Discussion was held on the next actions to be taken on each invasive alien pest and other general issues. The status of each pest was re-discussed and the way forward was recommended.

Part I. The way forward on the invasive alien pests presented during the plenary session

Citrus canker

In Sept 2009, EIAR requested the MoA to take quarantine measures on citrus canker. However, the status of the action taken by MoA is not known. What should be done next?

Suggested way forward

Ethiopian Institute of Agricultural Research needs to re-initiate the request and closely follow-up the progress. In this 2nd appeal, APHRD of the MoA can be directly approached for the action to be taken. In the mean time EIAR need to establish a national taskforce to handle all issues of Citrus canker.

Larger Grain Borer, ways forward .

1. Monitoring of the pest is the most important task. Thus movement of maize and cassava should be restricted by MoA to prevent further spread of LGB to other areas. Good quarantine system need to be put in place as it was done in other countries such as India.
2. A project proposal is being prepared to seek fund from potential donors. This proposal involves importation of natural enemies.

Fruit flies, ways forward

1. There are many research interests such as studying the species composition. USAID was interested to support the effort. As a result one task force has been established that involves Dr. Gashawbeza Ayalew (EIAR), Dr. Ferdu Azerfegne (HU), Dr. Emiru Seyoum (AAU) and Yeraswork Yilma (MoA).
2. A national workshop was supposed to be organized with the support of USAID. It is expected that experts from Kenya and South Africa will be involved in the workshop which will be held in the near future. In 2011 four MSc students of Hawassa University will conduct their theses researches on various aspects of fruit flies.

Pea weevil, ways forward

1. Efforts must be made to restrict Bruchus *pisorum* in the areas identified so far to have been infested by the insect. The survey has to continue in Arsi and Bale and southern parts of the country.
2. A Swedish agency has pledged to finance a project on IPM to

be launched soon in the Amhara (Ebinat) and Northern part of the country and Dr. Emiru Seyoum is the national PI of the project.

Wooly white fly, ways forward

An Israelis scientist has conducted a survey last year and pledged to launch biocontrol program. A parasitoid is expected to be imported and released in May 2011 at Upper Awash.

Cypress aphids, ways forward

The aphid population dynamics in year 2009 was low, 1 aphid per plant. Moreover, in some parts, infested cypress trees recovered and turned green and a very clear contrast was observed among *Cupressus lustanica* trees indicating the possibility of getting cypress aphid resistant provenances. Therefore further study suggested to be conducted in order to determine whether it is due to aphid induced host plant resistance.

Wooly apple aphid, ways forward

The use of the right and clean rootstock is the best way to reduce the problem. Therefore, strict quarantine system needs to be put in place in order to restrict the uncontrolled movement of planting materials. A project proposal is being prepared to be financed by JICA to establish quality nursery site to raise true-to-type wooly apple aphid resistant rootstocks for massive distribution.

Invasive alien weed species

Organized and concerted action need to be taken to prevent future re-infestation of water bodies with water hyacinth and it was suggested that Wonji Shoa Sugar Factory should closely monitor in its dam.

The effort to introduce and use herbivorous insects that specifically feed on parthenium should be strengthened

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ISBN 978-99944-987-3-4

Printed by ETH-CANA plc.