Pest risk analysis for *Solanum elaeagnifolium* and international management measures proposed

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Solanum elaeagnifolium Cav., originating from the Americas, has been unintentionally introduced in all the other continents as a contaminant of commodities, and is considered one of the most invasive plants worldwide. In the Euro-Mediterranean area, it is a huge threat in North African countries. It is also present in European Mediterranean countries (France, Greece, Italy and Spain), but still has a limited distribution. Through a logical sequence of questions, pest risk analysis (PRA) assessed the probability of *S. elaeagnifolium* entering, establishing, spreading and having negative impacts in European and Mediterranean countries. As this assessment revealed that the entry of the pest would result in an unacceptable risk, pest risk management options were selected to prevent the introduction of the plant. Preventive measures on plants or plant products traded internationally may directly or indirectly affect international trade. According to international treaties, PRA is a technical justification of such international preventive measures.

Almost all possible commodities are traded internationally, representing a value of EUR 6.5 trillion (USD 8.9 trillion) in 2004 (Burgiel *et al.*, 2006). In addition to movements of commodities, almost 700 million people cross international borders as tourists each year (McNeely, 2006).

Movements of agricultural products and people provide a clear economic benefit, but lead to the introduction of unwanted organisms that may threaten the agriculture and environment of countries. The phenomenon of invasion is best known in terms of diseases and insects, rather than for invasive alien plants. The introduction from the USA of *Phylloxera* into France in 1963, which threatened European vineyards, is a famous example. This accident raised awareness of the necessity of tackling plant protection problems on an international scale (Castonguay, 2005).

Solanum elaeagnifolium Cav. (Solanaceae) has been unintentionally introduced in the five continents as a contaminant of commodities, and is now considered one of the most invasive plants worldwide. It originates from the Americas and currently represents a huge threat to agriculture in North Africa, particularly in Morocco. It is already present, though not widely distributed, in some European countries (France, Greece, Italy and Spain). European and Mediterranean countries work collaboratively on plant health matters through the European and Mediterranean Plant Protection Organization (EPPO). Could the plant become a threat in other countries of the EPPO region? If yes, what measures could to taken to prevent the entry of this plant?

A pest risk analysis (PRA) addresses the following questions: What is the probability of the plant entering, establishing, spreading and becoming invasive in the area under study? If this assessment reveals that the entry of the pest would result in an unacceptable risk, pest risk management selects options to prevent the introduction of the species or to control it.

The International Standard on Phytosanitary Measures (ISPM no. 5, 2005) 'Glossary' defines terms used in this article such as 'commodity', 'entry', 'introduction', 'establishment', 'widespread'.

A potential problem: *Solanum elaeagnifolium*

History of the plant…

1949: in El Borouj (Chaouia province, inner Morocco) M. Gatefosi – a passionate botanist – notices a plant he has never seen before. It is a 1 m high Solanaceae, with beautiful purple flowers. He consults floras of Morocco and Tunisia without success. He investigates further and finally identifies the plant as *Solanum elaeagnifolium* Cav., originating from the Americas. He publishes this new record as the 459th contribution to the 'Annotated Catalogue of Plants of Morocco' (Qorchi & Taled, 1997). This is the first known occurrence of the plant in the Mediterranean basin.

1984: Moroccan researchers are concerned by *Solanum elaeagnifolium* Cav. which has spread since its first record in 1949 in El Borouj, and now covers about 8000 ha of the irrigated plain of the Tadla area – one of the most important Moroccan agricultural areas, producing cereals, maize, grazing for sheep, and cotton. The pest significantly lowers yields in crops such as maize and cotton.

Further research is undertaken to describe the biology of the plant (see Box 1), and several congresses of the Moroccan

Box 1: Biology of *Solanum elaeagnifolium* Cav.

(Information taken from the EPPO Datasheet on the plant, 2006.)

Description: *Solanum elaeagnifolium* is a multi-stemmed, broadleaved, herbaceous and woody perennial, growing up to 1 m tall. The aerial growth normally dies back during winter. The plant has an extensive root system spreading to over 2 m deep. The term 'rhizome' cannot be used in the case of this plant, as fragments of any part of the roots can regenerate.

Stems are herbaceous and woody at the base. Leaves are dark to pale greyish, petiolate, with margin. They are 2.5–10 (max. 16) cm long and 1–2.5 (max. 4) cm wide. Leaves, stems and calyx are densely pubescent, giving the plant its typical silver-green appearance. Yellow to brown-coloured prickles usually occur on the stems and also on the main veins of the leaves.

The inflorescence is a solitary cyme of 1–7 flowers. Flowers are 25–35 mm and are generally bright blue to purple, but sometimes white with yellow anthers of 7–9 mm.

The fruit is an irregularly dehiscent berry, initially spherical, green (with white patches) and fleshy, drying and becoming yellow to orange (10–15 mm in diameter) at maturity, looking like a little tomato. A single plant produces on average 40–60 fruits, each containing 60–120 seeds, smooth, flat, greenish-brown, 2–3 mm in diameter.

Life cycle: *Solanum elaeagnifolium* is a perennial geophyte with roots. Vegetative regeneration and germination occur in spring, the plant grows in summer, flowering takes place from spring to the end of summer and fructification from the end of spring till autumn; the plant then dies back in late autumn, and survives off its rootstocks during the winter.

Reproduction: It mainly reproduces vegetatively, from buds on underground fragments. Fragments as small as 0.5 cm long, as well as those buried up to 20 cm deep, can regenerate. Sections of taproot may maintain their viability for up to 15 months (Molnar & McKenzie, 1976). Ten-day-old seedlings are able to regenerate. Sprouting is enhanced by removal of the aerial parts of parent plants, or by cultivation that stimulates coppice growth from cut root sections. This aggressive vegetative growth from deep rootstocks makes *S. elaeagnifolium* very difficult to control, both mechanically and chemically.

Reproduction by seed is secondary, though seeds are highly viable and last at least 10 years. High levels of dormancy and infrequent germination can lead to the establishment of extensive viable seed banks. Studies indicate that 10% of seed is still viable after passing through sheep gut (Washington State Noxious Weed Control Board, 2006). Individual plants produce up to 200 berries per growing season, approximating to 1500–7200 seeds per plant.

Natural spread: The fruit can float, and can be dispersed over long distances along rivers and streams, especially during floods. Although the plants die back in winter, ripe fruits are retained on dead branches and may be dispersed by wind. Dried plants may also blow like tumbleweeds, spreading seed along the way (Boyd & Murray, 1982).

Seeds are also suspected to be widely dispersed by agricultural machinery and tools, vehicles, rooted nursery plants, contaminated straw or seeds, in bales of hay and alfalfa, and in the dung of livestock and wild animals.

Habitats: *Solanum elaeagnifolium* is mainly found in cultivated land (cereals, potato, cotton, etc.), orchards, managed grasslands and associated man-made habitats, on which it has a strongly negative impact. It is also recorded in natural grasslands, riverbanks/canalsides, rail/roadsides and wastelands.

Malherbology Association are dedicated to the plant (in 1996, 1997, 1998 and 2002).

… spread of the pest

2000: Since 1984, *S. elaeagnifolium* has continued to spread and now covers about 15 000 ha in the Tadla and adjacent zones, and is considered the nation's most noxious weed (Taleb & Bouhache, 2006). Tourists visiting Morocco look at the plant and ask local people 'what is this crop'? (Taleb, pers. comm. 2006).

By 2000, *S. elaeagnifolium* had come to be considered one of the most dangerous weeds in the world.

2006: Considering the enormous impact of the plant on agriculture and its potential for spread, it is feared that the plant may become a serious threat to other Mediterranean countries. The European and Plant Protection Organization (EPPO) and the Food and Agriculture Organization (FAO) North Africa organized an international workshop in Souss (Tunisia) to perform a PRA (see Box 2) for *S. elaeagnifolium* and to elaborate a management strategy.

At that time, the plant occurred in the following countries (Fig. 1):

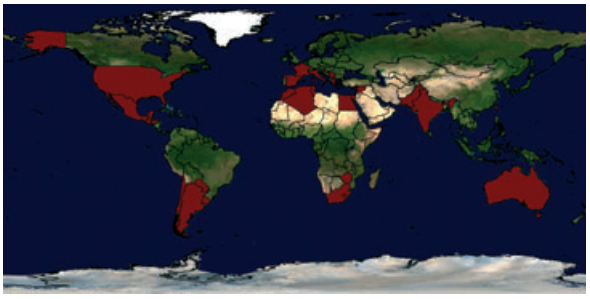

Fig. 1 World map of the occurrence of *Solanum elaeagnifolium* Cav. at the country level.

Box 2: International context of pest risk analysis

Legally binding rules for international trade have been developed by governments in the World Trade Organization (WTO) and affect trade in plants and plant products. WTO has 151 member countries. Two WTO agreements are particularly relevant to this trade: the Agreement on Agriculture, and the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement). In the SPS Agreement, it is stated that countries are allowed to restrict trade in plant and plant products when it is necessary to protect plant health. Nevertheless, such restrictions should be based on international standards, guidelines and recommendations, in order to avoid restrictions being used as a barrier to trade. The International Plant Protection Convention (IPPC) is recognized by the WTO agreement as the relevant international standard-setting organization for plant health matters. The IPPC has developed several standards, the most relevant Standard on Pest Risk Analysis is the International Standard on Phytosanitary Measures no.11, *Pest risk analysis for quarantine pests including analysis of environmental risks and living modified organisms* (ISPM no. 11, 2004).

Europe: Croatia, Cyprus, Egypt, France (isolated finding under eradication), Greece, Italy, Republic of Macedonia, Serbia and Montenegro, Spain.
Asia: India (Karnataka, Tamil Nadu), Israel, Syria, Taiwan.
Africa: Algeria, Algeria, Egypt, Lesotho, Morocco, South Africa, Tunisia, Zimbabwe.
North America: Mexico, USA (Alabama, Arizona, Arkansas, California, Colorado, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maryland, Mississippi, Missouri, Nebraska, Nevada, New Mexico, North Carolina, Ohio, Oklahoma, Oregon, South Carolina, Tennessee, Texas, Utah, Washington).
Central America and Caribbean: Guatemala, Honduras, Puerto Rico.
South America: Argentina, Chile, Paraguay, Uruguay.
Oceania: Australia (all states).

Pest risk analysis for *Solanum elaeagnifolium*

Since preventive measures may directly or indirectly affect international trade, they are subject to scientific justification according to the SPS Agreement (Box 2). This scientific justification can be provided by performing a PRA to determine whether a pest should be regulated, following the recommendation of ISPM no. 11 (2004), *Pest risk analysis for quarantine pests including analysis of environmental risks and living modified organisms* developed by the IPPC.

EPPO is an intergovernmental organization responsible for cooperation in plant protection in the European and Mediterranean region. It has 50 member countries (as of March 2011). It provides recommendations to National Plant Protection Organizations (usually part of the Ministry of Agriculture). EPPO has adapted and uses its own version of ISPM no. 11 (2004) (EPPO Standard PM 5/3: *Decision-support scheme for quarantine pests*).

The EPPO Decision-support scheme provides a simple scheme based on a sequence of questions to decide whether an organism has the characteristics of a quarantine pest, and if appropriate, to identify potential management options.

The EPPO Decision-support scheme is composed of three sections: initiation, PRA, and pest risk management.

The initiation section aims to identify whether the organism has the characteristics of a quarantine pest; in this case, the organism is then evaluated in greater detail in the PRA section. This section considers the potential of introduction of the organism [i.e. it follows the different steps of an invasion: entry, establishment, spread and invasive behaviour (assessed through impacts)]. If this assessment concludes that the organism represents an unacceptable risk, the PRA will identify measures to prevent entry, establishment or spread of the pest.

The EPPO Decision-support scheme was developed primarily for classical pests of agriculture (insects, fungi, viruses, bacteria, nematodes, etc.), but was recently adapted to include invasive alien plants.

Probability of entry: how can *Solanum elaeagnifolium* enter a new territory?

While considering the probability of entry of *S. elaeagnifolium* into new territories, the following questions arose:

- How did the pest arrive from the Americas to Morocco (first record of the pest in the Mediterranean area)?
- Can the pest enter via other international pathways?

National pathways (e.g. through irrigation waters and sheep manure) are considered in the section on spread, though they are also listed in the entry section.

Means for natural spread (e.g. wind dispersal) are also identified to evaluate their contribution to the risk of entry. As stated in ISPM no. 11 (2004), when natural spread is the major pathway, 'Measures are not justified if the risk is already acceptable or must be accepted because it is not manageable (as may be the case with natural spread)', but this is not the case for *S. elaeagnifolium*.

International pathways of entry of Solanum elaeagnifolium Cav

How did Solanum elaeagnifolium move from the Americas to Morocco in the late 1940s? The exact delimitation of the native range of the plant remains unclear. However, the most likely centre of geographic origin is the south-western USA or Northern Mexico (Boyd & Murray, 1982). Goeden (1971) remarked that the insect fauna on the target plant increased rapidly as they approached the Texan/Mexican border.

There are two hypotheses for the first introduction of the plant to Morocco:

- The plant may have been introduced involuntarily with sheep imported from Algeria. Whether Algeria was invaded

prior to Morocco remains unknown (Taleb & Bouhache, 2007). How the plant arrived in Algeria is also unknown.

- The plant may have been introduced involuntarily as a contaminant of cotton seeds imported from the USA. This hypothesis remains the most likely, since the first cotton fields appeared in the 1940s in Morocco, the period of first reports of the plant in this country. Moreover, cotton fields in the USA were widely invaded by *S. elaeagnifolium*. This is therefore considered the most probable hypothesis.

Other international entry pathways considered. In assessing the probability of entry of a pest, all international pathways by which this pest could enter should be investigated.

For each international pathway identified, PRA evaluates the probability of the pathway carrying the pest by considering: the likelihood and the concentration of the pest associated with the pathway at origin; the volume and frequency of movement along the pathway; the probability of survival of the pest during transport; the probability of the pest surviving existing pest management procedures; and the probability of the pest transferring to a suitable habitat.

In the case of *S. elaeagnifolium*, for all the pathways considered in the PRA and presented below, the plant is very likely to survive during transport or storage. Indeed, seeds and vegetative reproductive parts of the plant may remain viable for very long time (10 years for seeds, up to 15 months for vegetative parts). The assessment of the probability of entry of the different pathways led to the following conclusions.

International pathways of entry for which probability is very likely

Contaminant of plants for planting with growing media from contaminated nurseries originating in countries where *S. elaeagnifolium* occurs.

In Morocco, the long-distance spread mechanism through contaminated plants for planting is shown by the occurrence of the plant in the growing media of ornamental species (Fig. 2). This pathway allowed the plant to invade public gardens and orchards at a distance of 50 km from the initial infested area (Taleb & Bouhache, 2007).

A wide variety of plants, such as *Nerium oleander* (oleander), *Citrus aurantium* (sour orange) and *Olea* spp. (olive trees), are traded in huge quantities throughout the Euro-Mediterranean region. There are no specific requirements in place to prevent the entry of *S. elaeagnifolium* through internationally traded plants for planting. Once ornamental species are planted in nurseries, on roadsides or in gardens, the pest can escape very easily into surrounding habitats.

The probability that *S. elaeagnifolium* could enter as a contaminant (seeds or parts of roots) of plants for planting coming from countries where *S. elaeagnifolium* occurs (e.g. North and South America, Morocco) is therefore very high.

Contaminant of soil/growing media (with organic matter) as a commodity from countries where *S. elaeagnifolium* occurs.

In the Tadla region, it has been observed that the plant colonizes *oueds* (*oued* is Arabic for 'river', and is a characteristic water course in semi-desertic areas of North Africa which is most often dry, with occasional extraordinary floods). Seeds or parts of roots of *S. elaeagnifolium* can be present in the *oueds*. Farmers collect sand from these *oueds* for use in their farms. This sand is the reported cause of the contamination of 5 farms out of 92 infected in Morocco according to Taleb & Bouhache (2007).

Fig. 2 An infestation of *Solanum elaeagnifolium* on a roadside, probably introduced with the growing media of the ornamental plant. Kairouan, Tunisia, May 2006. Photo: Sarah Brunel.

Regulation regarding the import of soil varies between EPPO countries. Whereas some countries have a total prohibition on import, the European Union Plant Health legislation does not prohibit the import of soil from most Mediterranean countries (including Morocco and Tunisia), and movement of soil between EU countries is not restricted either (Council of Europe Union, 2000). Once introduced as a contaminant of soil, the plant may then spread very easily.

The probability of *S. elaeagnifolium* being introduced as a contaminant of soil or growing media is consequently very high.

Contaminant of soil on machinery.

In Morocco, 20 soil samples taken from agricultural machinery were examined, and contained 592 seeds of *S. elaeagnifolium*, of which 52% were viable (Taleb & Bouhache, 2007). Machinery is usually shared by different farmers, increasing the likelihood of spread of the plant. Vehicles in general are also considered a pathway. There are no phytosanitary measures in place for machinery moving from one country to another.

The probability that *S. elaeagnifolium* enters as a contaminant on used machinery is therefore very high.

Contaminant of seeds (for planting) of *Zea mays*, *Medicago sativa*, *Triticum aestivum*, *Sorghum bicolor*, *Gossypium* spp. and *Nicotiana tabacum* from countries where *S. elaeagnifolium* occurs

Solanum elaeagnifolium has been recorded as strongly infesting fields of *Z. mays* (maize), *M. sativa* (alfalfa), *T. aestivum* (soft wheat), *S. bicolor* (common sorghum), *Gossypium* spp. (cotton) and *N. tabacum* (tobacco). The harvest period of these crops coincides with the period of maturity of *S. elaeagnifolium* seeds. Since *S. elaeagnifolium* seeds are small (2–3 mm), they may remain undetected in the seeds for planting of the crops listed above. This is enhanced by the fact that no specific requirements concerning this pest exist in seed certification schemes other than in Belarus, Russia and the Ukraine, where import of seeds for sowing contaminated with *S. elaeagnifolium* seeds is prohibited (those countries can therefore be seen to have considered this pathway as probable). There are no existing phytosanitary measures to prevent the introduction of the plant into other Euro-Mediterranean countries.

The probability that *S. elaeagnifolium* enters as a contaminant of seeds for planting is therefore very high.

International pathways of entry for which probability is moderately likely

Contaminant of footwear from countries where *S. elaeagnifolium* occurs.

As seeds occur in soil on machinery (see previous pathways), they could also occur in soil stuck on people's shoes. With an estimated 700 million people crossing international borders as tourists each year (McNeely, 2006), the probability of introducing *S. elaeagnifolium* as a contaminant on footwear clearly exists. Although not demonstrated, this is one of the possible pathways of introduction for the outbreak in Berre l'Etang in the south of France (Luc Brun, manager of the natural reserve in Berre l'Etang, pers. com. 2005).

The probability that *S. elaeagnifolium* enters as a contaminant of footwear is therefore moderately high.

Contaminant of consignments of grain (*Z. mays*, *T. aestivum*, *S. bicolor*) from countries where *S. elaeagnifolium* occurs

Solanum elaeagnifolium has been recorded as strongly infesting fields of *Z. mays* (maize), *T. aestivum* (soft wheat) and *S. bicolor* (common sorghum). Periods of harvest of *Z. mays*, *T. aestivum*, *S. bicolor* and fructification of *S. elaeagnifolium* coincide. Seeds of the pest may therefore be present in consignments of such grain. Even if these crops are subject to herbicide treatments, *S. elaeagnifolium* is very difficult to manage and may remain in the fields. These commodities are traded in vast quantities (as an indication, in 2008 in the European Union, approximately 22.6 million tonnes of maize, 29.3 million tonnes of wheat and 4.0 million tonnes of sorghum were imported, according to FAOSTAT) and are not subject to phytosanitary requirements that could affect the pest. These figures concern total imports, not only imports from infested countries, but the pest is recorded in many countries. Grain of these crops is usually processed (crushed) and used for animal or human food. Its end use is consequently not likely to help the plant escape and spread into the wild, except during transport of the grain and when it is stored in silos.

The probability that *S. elaeagnifolium* enters as a contaminant of consignments of grains is therefore moderately high.

Contaminant of containers and packaging.

Containers and packaging are associated with many commodities traded to many destinations. As they may be stored in nurseries, orchards, or places of production where *S. elaeagnifolium* occurs, they could be contaminated by the pest. There are no measures in place to control containers and packaging, and once they are stored in the country of import, the plant may easily escape.

The probability that *S. elaeagnifolium* enters as a contaminant of containers and packaging is therefore moderately likely.

Other pathways identified but not considered as representing a risk

Use of the species as an ornamental plant.

Solanum elaeagnifolium has no ornamental value and introductions worldwide appear to have been unintentional. Anecdotally, Chalghaf *et al.* (2007) report that in Tunisia, a farmer introduced the plant on her land because of the showy beauty of the flowers. Other farmers spread the plant by using it to form a protective barrier against sunlight for their vegetable production.

The entry of *S. elaeagnifolium* as a traded ornamental plant is therefore considered unlikely.

Contaminant of hay and pig fodder.

In South Africa, the pest is thought to have been imported as a contaminant of pig fodder around 1905 (Wassermann *et al.*, 1988), and/or hay during the 1940s or 1950s. *Solanum elaeagnifolium* was recorded as a problem in 1952 and declared a weed there in 1966.

Even if the invasive plant has been recorded in crops such as *Medicago sativa* (alfalfa) and *Sorghum sudanense* (Sudan grass), harvest is considered to occur too early to allow a significant presence of *S. elaeagnifolium* in the hay. Moreover, international trade of hay is considered to be occasional in the Euro-Mediterranean region.

The entry of *S. elaeagnifolium* as a contaminant of hay and pig fodder is therefore considered unlikely.

Contaminant of maize for forage and silage.

Even if *S. elaeagnifolium* could be a contaminant of *Z. mays* for forage and silage, as it is harvested in August (when the fruits are mature), no international trade of this commodity is reported.

The entry of *S. elaeagnifolium* as a contaminant of maize for forage and silage is therefore considered unlikely.

Other pathway to study. Performing a PRA is very time-consuming and can be undertaken over several months or years, and PRAs can be completed and reviewed over time. The cotton pathway has not been investigated yet and deserves further research.

Contaminant of commodities of cotton.

Solanum elaeagnifolium is recorded as a major weed in cotton. Whether processes (e.g. cleaning) kill all the contaminants remains to be determined.

Human-assisted pathways of spread

Studies in the 1980s undertaken in 92 contaminated farms in the Tadla region in Morocco identified the following national pathways:

Sheep. During the dry season in North Africa, there are hardly any plants to eat in the pastures, and sheep eat *S. elaeagnifolium* branches and fruits. Seeds do not lose their viability while transiting in sheep gut (Taleb & Bouhache, 2006). It has been found that, on average, 26 seeds are present in 1 kg of sheep faeces, which the animals spread in fields or roadsides (Essadini, 1988 in Taleb & Bouhache, 2007). Prickles on the plants allow parts of the plant to be carried and spread by sheep fleece as well. Forty-eight farms (52% of farms contaminated according to the study undertaken by Taleb & Bouhache, 2007) were considered to be primarily infested by movement of sheep.

As this pathway is linked to animals, it is not possible to regulate it on the basis of plant health legislation.

Sheep manure. Sheep manure is widely used to fertilize orchards and crop fields, and has been reported as a pathway for spread of *S. elaeagnifolium* in 53 Moroccan farms (about 57% of farms contaminated; Mahfoud, 1988 in Taleb & Bouhache, 2007). About 36 seeds of *S. elaeagnifolium* were found per kilogram of manure, and 58% of these seeds were viable (Essadini, 1988 in Taleb & Bouhache, 2007). No seeds of *S. elaeagnifolium* were found in cattle and horse manure.

Irrigation water. In *S. elaeagnifolium* pseudo-berries, air is held between the agglomerated 60–120 seeds and the external envelope. This enables the fruit to float and to be dispersed by water. One hundred and thirty-one (131) seeds were found in 6 traps set on an irrigation canal for 8 hours, of which 91 were viable. Thirty-three (33) farms (36% of farms contaminated according to the study undertaken by Taleb & Bouhache, 2007) record having been contaminated by irrigation waters.

Special attention to these pathways should be given at the national level.

Natural pathways of spread

Wind. In the Tadla, south and south-east winds are very strong between May and October, carrying seeds, fruits and even entire plants (Taleb & Bouhache, 2007). Wind is therefore considered a probable natural pathway.

Other natural pathways. Irrigation water has proven to be a pathway (see previous pathways), and natural rivers are also susceptible to carrying fruits or parts of roots of the plant. The role played by wild animals in the spread of the plant remains unknown, since viable seeds were found in sheep manure, but not in cattle or horse manure.

Can *Solanum elaeagnifolium* establish and spread in the Euro-Mediterranean region?

A plant which enters a country does not necessarily escape, establish and spread. Of those species that escape, many are reported only as casual and then disappear since they cannot maintain sustainable populations. Only a small fraction can establish in the wild, and it is this probability that has to be assessed through the following questions.

Probability of establishment

Suitability of the environment. Suitable habitats for the plant are very common and widespread in the Euro-Mediterranean area:

- Man-made habitats: roadsides, wastelands, gardens, orchards and spring crops. Being a spring species, the life cycle of *S. elaeagnifolium* coincides with the life cycle of spring crops (wheat, vegetables, maize and sesame).
- Uncultivated habitats: pastures and managed grasslands, riversides and canal banks.

The plant can adapt to different soil types and is not likely to be limited by this factor. It forms monospecific stands and it is not considered to be affected by competition with other plants; no natural enemies have been recorded on the plant so far in North African countries.

The most susceptible limiting factor appears to be climate. For normal germination and growth, *S. elaeagnifolium* tolerates Mediterranean, steppe and mild climates with relatively high summer temperatures (20–34°C) and low annual rainfall (250–600 mm) (Parsons, 1981; Heap *et al.*, 1997). The plant is very adaptable. Once established, it is sensitive to frost and waterlogging, but highly resistant to drought, and thrives under irrigated conditions in semi-arid areas. It is even resistant to saline conditions (Wassermann *et al.*, 1988). It is therefore suspected that the plant could establish in all Mediterranean countries.

A simple climate-match analysis has been performed with CLIMEX (see the CLIMEX User's Guide by Sutherst *et al.*, 2004). The CLIMEX model is a computer program aiming at predicting the potential geographical distribution of an organism considering its climatic requirements. It is based on the hypothesis that climate is an essential factor for the establishment of a species in a country.

According to the 'Match index' based on Tadla and Kairouan, countries with a CLIMEX match index up to 70% are considered to be largely similar to the locations where the species is invasive, and are therefore the most at risk. These countries are: Albania, Algeria, Bosnia and Herzegovina Bulgaria, Croatia, Cyprus, France, Georgia, Greece, Hungary, Israel, Italy, Jordan, Kazakhstan, Moldova, Malta, Morocco Portugal, Spain, Romania, Russia, Serbia and Montenegro, Slovenia, Tunisia, Turkey, Ukraine and Uzbekistan.

It should be noted that a climate-match analysis is not accurate enough to predict potential distribution, and that the plant ideally requires a detailed 'compare location' analysis. This could not be done at the time of performance of the PRA due to lack of expertise in using CLIMEX within the EPPO Secretariat.

Cultural practices and control measures. Cultural practices such as fertilization and irrigation of crops could favour the establishment of *S. elaeagnifolium*. There are no specific existing control measures for this plant, except in Ukraine, Russia and Belarus, where seeds of crops have to be free from *S. elaeagnifolium*.

Due to its biological characteristics (high seed production, long-lasting seed bank, ease of spread of seeds and fragments of roots, etc.), the plant is known as very difficult to manage once established. Eradication is possible only for early infestations. For

instance, in Russia, contingency plans state that if an outbreak is detected, the field should be removed from production for 3 years. It has to be treated with imazapyr 0.75 kg ha^{-1} of active matter at the 2–4-leaf stage. Following this 3-year period, perennial or winter wheat has to be sown in the field (Savotikov & Smetnik, 1995).

Other characteristics of the pest affecting the probability of establishment. The plant has shown extraordinary reproductive, competitive and resistance abilities, and is considered invasive in every environment where it is present, even in its indigenous range.

Probability of spread

The situation in North Africa has shown that spread of the plant is fast and easy, since the plant has extraordinarily diverse and efficient reproduction and adaptability. In Morocco, the plant invaded approximately 15 000 ha in 55 years through natural and human-assisted spread (see Human-assisted pathways of spread).

What are the impacts of the plant?

Previous parts of the assessment highlighted that entry, establishment and spread of *S. elaeagnifolium* in Euro-Mediterranean countries are likely to occur. Establishment of a new species in a territory is to be prevented only if it has negative effects. It is therefore necessary to determine whether the introduction of this species is likely to have unacceptable economic consequences. Within the IPPC terminology, economic impacts include environmental and social impacts.

Effects on agriculture

Crops affected. Solanum elaeagnifolium competes for moisture and nutrients with many crops. The following crops are susceptible to infestation by the pest. These represent a huge agricultural activity in the EPPO region (data provided by FAOSTAT, http://www.faostat.fao.org [accessed March 2011] for the EU as an indication for 2009, although should be kept in mind that not all European countries could be affected by *S. elaeagnifolium*); where available, units are in tonnes produced in the EU in 2009:

- *Gossypium hirsutum* (cotton): cultivated in Morocco, Greece, Spain and Uzbekistan
- *Medicago sativa* (lucerne)
- *Sorghum bicolor* (common sorghum)
- *Triticum aestivum* (wheat): 229 million tonnes in the EU
- *Zea mays* (maize): 84 million tonnes in the EU
- and to a lesser extent *Arachis hypogaea* (groundnut), *Asparagus officinalis* (asparagus, 0.26 million tonnes), *Beta vulgaris* var. *saccharifera* (sugar beet), *Citrus* spp. (citrus), *Cucumis sativus* (cucumber), *Lycopersicon esculentum* (tomato, 22.8 million tonnes), *Olea europaea* subsp. *europaea* (olive, 12.6 million tonnes), *Prunus persica* (peach, 4.3 million 4 270 861 tonnes), *Solanum tuberosum* (potato, 124 million tonnes), *Sorghum sudanense* (Sudan grass) and *Vitis vinifera* (grapevine).

Infestations are more serious in dryland situations, although irrigated croplands are also highly prone to invasion, and many other horticultural and orchard crops are affected.

Impacts. In the USA, 75% of losses were observed in cotton grown under semi-arid conditions (Robinson *et al.*, 1978). *Solanum elaeagnifolium* also displays allelopathic effects, especially in cotton fields (Bothma, 2002; California Department for Food and Agriculture, 2006).

In Morocco, according to Baye & Bouhache (2007), maize yield harvest was found to be reduced by 63% in the absence of weeding. *Solanum elaeagnifolium* has also been reported as a reservoir of *Potato virus Y* (PVY) in Tunisia (Boukhris-Bouhachem *et al.*, 2007).

In pastures, both perennial and annual species are adversely affected, with pasture establishment delayed and pasture production reduced.

Additionally, the berries of *S. elaeagnifolium* are toxic to livestock, particularly when ripe (Burrows *et al.*, 1981). Symptoms include excessive salivation, nasal discharge, respiratory complications, bloating, trembling and diarrhoea (Parsons, 1981). The plant affects horses and causes mortality to sheep (Molnar & McKenzie, 1976), while goats are apparently unaffected (Parsons, 1981; Wassermann *et al.*, 1988).

Environmental and social impacts

Although *S. elaeagnifolium* is primarily associated with cultivated land, it may also invade adjoining areas (e.g. roadsides, river- and canal sides) and may replace natural vegetation in areas of overgrazed rangeland.

Solanum elaeagnifolium has been reported on the islet of Plavnik (Croatia) (EPPO, 2006a), which is known as a biodiversity hot spot for its bird species, amphibians and reptiles (EPPO, 2006c). This unique biodiversity may be threatened by *S. elaeagnifolium.*

The plant was also present in the south of France in Châteauneuf-les-Martigues, in wet pastures protected by the Habitats Directive, but it has been eradicated there (EPPO, 2006b).

In terms of social impacts, agricultural land infested with *S. elaeagnifolium* loses considerable rental and resale value. In Morocco, the value of infested fields decreased by 25% (Gmira *et al.*, 1998). In the USA, farms have been abandoned because of infestations by *S. elaeagnifolium* (Parsons, 1981).

While on the field trip in the Kairouan area, which formed part of the EPPO/FAO Workshop on *S. elaeagnifolium* in May 2006, participants saw a rural woman picking out *S. elaeagnifolium* from wheat fields until it formed a huge bundle. She was wearing a flannel glove to try to protect her hand from the prickles of the plant. She reported that picking out this plant represented several hours of work each week (Fig. 3).

Degree of uncertainty

Estimation of the probability of introduction and spread of a pest and of its economic consequences (including environmental and social impacts) involves many uncertainties. Describing these

Fig. 3 Farmer picking out *Solanum elaeagnifolium* from wheat fields by hand. Kairouan area (Tunisa), May 2006.

uncertainties is necessary for transparency and may also be useful for identifying and prioritizing research needs.

The main remaining uncertainties in the PRA for *S. elaeagnifolium* concern the ability of the pest to colonize temperate climates and the possibility for cotton commodities to act as a pathway.

Conclusion of the assessment

Considering all the elements given above, *S. elaeagnifolium* is very likely to spread further within the whole Mediterranean basin and to cause major economic impacts, considering all the crops affected by this pest and the environmental and social negative effects.

The plant qualifies as a quarantine pest, and selection of risk management options should therefore be envisaged.

How to manage the risk posed by *Solanum elaeagnifolium* in the European and Mediterranean area?

Although preventive measures are considered the most efficient, they are not always implemented since they rely on international procedures affecting trade of commodities. National management measures are also necessary.

Preventive measures

The pest risk management section identifies measures to prevent entry, establishment or spread of the pest. It explores options that can be implemented: (i) at origin or in the exporting country, (ii) at the point of entry, or (iii) within the importing country or invaded area. The options are structured so that, as far as possible, the least stringent options are considered before the most expensive/disruptive ones.

Preventive measures proposed for the pathways identified in the PRA are presented in Table 1 (in addition to the definitions given in ISPM no. 5 (2005); more explanations are available on these measures in ISPM no. 4 (1995), *Requirements for the establishment of Pest Free Areas*; ISPM no. 10 (1999) *Requirements for the establishment of pest free places of production and pest free production sites*; and ISPM no. 12 (2001) *Guidelines for phytosanitary certificates*, IPPC 2007).

National measures

During the Workshop held in Souss (Tunisia) in 2006, recommendations concerning national measures were drafted and are available on the EPPO website (http://www.eppo.org).

These recommendations include the constitution of a National Technical Committee on *S. elaeagnifolium* coordinated by a National Plant Protection Organization which should implement the National Action Plan, including:

- An annual delimiting survey (according to the International Standard for Phytosanitary Measures no. 6 *Guidelines for surveillance*), in fields, near silos, near slaughterhouses (since many sheep transit there), etc.
- The establishment of warning and training programmes for agricultural technicians, farmers, shepherds (in particular with the FAO Farmer Field School programme).
- Eradication measures for limited outbreaks.
- Management measures for infested areas and their follow up: mechanical, cultural, chemical and biological control.

Outcome of EPPO's and FAO's initiatives on *Solanum elaeagnifolium*

The PRA on *S. elaeagnifolium* has gone through the EPPO process of approval, and the recommendation that the plant should be regulated was approved by the EPPO countries in 2006. All EPPO documents (PRA, report of PRA, national strategy, etc.) are available on its website (http://www.eppo.org). It is now countries' responsibility to include such recommendations in their national regulations. So far, these recommendations have not been adopted by the National Plant Protection Organizations (usually part of the Ministries of Agriculture) of the EPPO region, but establishing import regulations takes some time. Although preventing introductions of invasive alien species is considered the most cost-effective option economically and environmentally, so far substantially more attention and resources have been dedicated to control (Burt *et al.*, 2007). This is well illustrated in the case of *S. elaeagnifolium.*

EPPO works in close partnership with the Convention on the Conservation of European Wildlife and Natural Habitats (known as the Bern Convention, see website http://www.coe.int/t/dg4/cultureheritage/nature/bern/default_en.asp [accessed March

Table 1 Preventive measures identified for pathways of introduction of *Solanum elaeagnifolium*

Pathways/measures	Measures related to consignments	Measures related to crop or place of production	Other possible measures
Very likely: Plants for planting with growing medium attached from countries where *S. elaeagnifolium* occurs	No measures identified Soil freedom was not sufficient as root fragments of *S. elaeagnifolium* may remain mixed with the plant root system.	Area freedom for *S. elaeagnifolium*; or Pest-free place of production for *S. elaeagnifolium*; or The plants have been grown in a growing medium free from the pest.	Surveillance and/or eradication campaigns would not be sufficient to prevent establishment.
Very likely: Soil/growing medium (with organic matter) as a commodity from countries where it occurs	Heat treatment or sterilization of the soil is a recommended measure.	Area freedom for *S. elaeagnifolium*; or Place of production freedom for *S. elaeagnifolium*.	No internal measures such as surveillance and/or eradication campaigns have been identified.
Very likely: *S. elaeagnifolium* as a contaminant on machinery from countries where it occurs	Cleaning or disinfection of imported machinery or vehicles is recommended.	/	/
Very likely: Seeds of *Gossypium* spp., *Hordeum indicum*, *Medicago sativa*, *Nicotiana tabacum*, *Sesamum indicum*, *Sorghum bicolor*, *Triticum* spp., *Zea mays* from countries where it occurs	Cleaning of seeds has been identified as a possible measure reducing the risk to a sufficient level.	Area freedom for *S. elaeagnifolium*; or Place of production freedom for *S. elaeagnifolium*; or Crop freedom for *S. elaeagnifolium*.	Surveillance and/or eradication campaigns would not be sufficient to prevent establishment.
Moderately likely: *S. elaeagnifolium* as contaminant on footwear where it occurs	/	/	Publicity to enhance public awareness of pest risks is a recommended measure.
Moderately likely: Consignment of grain (*Hordeum* spp., *Sesamum indicum, Sorghum bicolor, Triticum* spp., *Zea mays*) from countries where it occurs	Cleaning of grain has been identified as a possible measure reducing the risk to a sufficient level.	Area freedom for *S. elaeagnifolium*; or Place of production freedom for *S. elaeagnifolium*; or Crop freedom for *S. elaeagnifolium*.	No internal measures such as surveillance and/or eradication campaigns have been identified.
Moderately likely: Containers and packaging	/	/	The use of clean containers and packaging material is recommended.

2011]) of the Council of Europe. The Bern Convention coordinates the action of European Ministries of the Environment in matters related to the conservation of biological diversity. It includes at present 44 Contracting Parties. In December 2007, *S. elaeagnifolium* was recommended for eradication in the signatory countries where it is not widespread.

Following the EPPO/FAO Workshop held in Souss, FAO North Africa is implementing a communication programme for farmers on *S. elaeagnifolium*. This project aims to monitor the pest through cartography, training educators and farmers to recognize the pest, and identifying appropriate management measures. Leaflets will be prepared to raise awareness.

Conclusions

Fifty-five years after its first accidental introduction in Morocco, *S. elaeagnifolium* is one of the most harmful invasive plants in North African countries and threatens other Mediterranean countries.

The EPPO PRA concludes that *S. elaeagnifolium* represents a risk for the agriculture and environment of all Mediterranean countries. The pest risk management section identified measures to prevent entry of the plant through international trade. A national strategy has also been drafted.

The problems posed by *S. elaeagnifolium* provided an opportunity to develop international cooperation among North African countries where the plant is already widespread. This was achieved notably through the implementation of a communication programme for farmers launched by FAO North Africa.

Although management operations are in place in North Africa and eradication measures are implemented in some Mediterranean countries, no specific import requirements for *S. elaeagnifolium* have been included in the phytosanitary regulations to date in the EPPO region (some measures already existed in Belarus, Russia and the Ukraine). Such preventive measures should be established in countries at risk before the plant is too widespread to be managed efficiently.

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Analyse de risque phytosanitaire pour *Solanum elaeagnifolium* et proposition de mesures de gestion internationales

Solanum elaeagnifolium Cav., originaire des Amériques, a été introduite involontairement dans tous les autres continents comme contaminant de marchandises et est considérée comme une des plantes les plus envahissantes dans le monde. Dans la zone euro-méditerranéenne, elle constitue une grave menace pour les pays d'Afrique du Nord. Elle est également présente dans les pays méditerranéens européens (Espagne, France, Grèce et Italie), mais y est encore peu répandue. Via une séquence logique de questions, l'Analyse de Risque Phytosanitaire (ARP) évalue la probabilité que *Solanum elaeagnifolium* entre, s'établisse, se dissémine et ait des impacts négatifs dans les pays euro-méditerranéens. Cette évaluation ayant révélé que l'entrée de cette plante engendrerait un risque inacceptable, des options de gestion du risque ont été sélectionnées pour prévenir son introduction. De telles mesures préventives peuvent directement ou indirectement affecter le commerce international de végétaux ou produits végétaux. D'après les traités internationaux, l'ARP constitue justement une justification technique à de telles mesures internationales.

Анализ фитосанитарного риска для *Solanum elaeagnifolium* и предлагаемые международные меры управления риском

Паслён *Solanum elaeagnifolium* Cav., американского происхождения, был ненамеренно завезен на все 5 континентов как загрязнитель товаров, и считается одним из самых инвазивных растений в мире. В европейско-средиземноморском регионе он представляет собой огромную угрозу для североафриканских стран. Он также присутствует и в европейских странах Средиземноморья (Франции, Греции, Италии и Испании), но там он все еще имеет ограниченную распространенность. С помощью логической последовательности вопросов Анализа фитосанитарного риска (АФР) оценивается вероятность проникновения, акклиматизации, распространения *Solanum elaeagnifolium*, а также оказания им негативных воздействий в различных странах. Такой анализ был проведен для европейских и средиземноморских стран. Поскольку эта оценка показала, что проникновение вредного организма приведет к неприемлемому риску, чтобы предотвратить интродукцию этого растения, были отобраны варианты управления фитосанитарным риском. Превентивные меры для растений или растительной продукции, находящихся в международной торговле, могут прямо или косвенно на ней сказываться. В соответствии с международными договорами, АФР представляет собой техническое обоснование таких международных превентивных мер.

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